APPLICATION OF 3D LASER SCANNING DATA IN STRUCTURAL FOREST MANAGEMENT DECISION

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ABSTRACT: Thinning operations are important in forest tending and its efficacy not only in increased timber growth and decreased competition, but also provides better growing space, sunlight, nutrient, and water resource for trees. There are some problems of quantification and spatial research on thinning operations while selecting timbers. It is a swift and popular method to gain three-dimensional (3D) information of forest by ground-based LiDAR system. The 3D scanning Light Detection and Ranging (LiDAR) system for capable of making non-destructive recordings of individual tree structure was described. In this study, we used ground-based LiDAR and traditional data of field surveys to obtain individual tree characteristic values of LiDAR included tree height, diameter at breast height, and individual tree location map in thinning operations, and applied correlation analysis of stand characteristics. We estimated the feasibility of ground-based LiDAR data in forest area by correlation analysis and predictable model. We used this technology to map three-dimensional individual tree positions. The 3D laser scanning can obtain highly accurate scans of cloud data, and provide the basic information of individual tree spatial distribution. It can determine tree competition, forest health, forest measurement, and thinning operations by ground-based LiDAR, which can be used in quantification of thinning operations and decrease time. It solved problems of quantification and spatial research on thinning operations by ground-based LiDAR, and proceeded simulation of thinning operations. It was also very easy to understand condition for decision maker.

1. INTRODUCTION

The measurement and structural characterization of trees can be carried out by means of several detection principles, such as image analysis techniques, stereoscopy photography, ultrasonic ranging and optical ranging et cetera. The LiDAR-based measurement had proved to be a valuable tool for the measurement of the physical and structural characteristics of trees including tree volume, leaf area density and LAI (Polo *et al.*, 2009). Ground-based LiDAR is a remote sensing technique based on the measurement of the time a laser pulse takes between the sensor and a target and has the advantage that the beam can be very thin and divergent (Palacin *et al.*, 2006). The time-of-flight method is often available, and provides more precise 3D images of individual trees with a typical resolution of 0.05-10.00 cm. 3D images generated from such systems provide much information about the trees, and each tree height can be estimated from the image, together with other variables (Omasa *et al.*, 2002; Urano and Omasa, 2003). Boehler *et al.* (2001) who were deem highly of ground-based LiDAR from the high working efficiency and density of data.
Ground-based LiDAR with high positional accuracy and high density automation will be widely applied in vast range of fields including terrain and building measurement, earthwork, engineering, architectonics, archeology and forestry (Omasa *et al.*, 2002; Urano and Omasa, 2003; Hosoi and Omasa, 2006; Barber *et al.*, 2008; Polo *et al.*, 2009; Al-kheder *et al.*, 2009; Côté *et al.*, 2009; Keightley and Bawden, 2010; Mariano *et al.*, 2011).
For forestry applications, Omasa *et al.* (2002) proposed a methodology for mapping and estimating laser sensor data to obtain several parameters related to the geometric characteristics of *Larix leptolepis* woods (diameter at breast height (DBH), biomass, individual tree location map).
Studies based on the 3D point clouds have improved the efficiency of data collection. Nevertheless, it is still difficult

for the methods to account for the effects of non-uniformity of the actual foliage distribution. As above, accurate estimation of the vertical foliage distribution is still difficult with either airborne or ground-based LiDAR systems (Omasa *et al.*, 2007). Hosoi and Omasa (2006) proposed a methodology for a voxel-based canopy profiling method, in which the 3D space is divided into voxels that are the 3D equivalent of the pixels in a 2D image, has been developed for estimating vertical foliage profiles with reduced the effects of any non-uniformity in the foliage distribution and non-photosynthetic tissue.

Generally, the structural, geometrical parameters of trees and stand characteristics, such as individual tree biomass, and leaf area density are derived from the manual measurement of volumes and the destructive sampling of leaves. However, the destructive sampling for forest was both slow and costly, other inexpensive methods, such as ground-based LiDAR scanning systems, have been used over the last 10 years and found to be robust.

In this study, in order to determine the suitability of laser sensors to characterize forest trees several parameters have been computed based on scanner data, and compared with tree height, DBH, and individual tree location map and tree volume by means of linear regression analysis. The procedures developed and the results obtained are presented here.

2. MATERIALS AND METHODS

2.1 Ground-based LiDAR

The Ground-based LiDAR Trimble GS200 system manufactured by Mensi SA, France, is used. This scanner features are 360º horizontal field of view (HFOV) and 60 º vertical field of view (VFOV), enabling the collection of full panoramic views. The distance measurement is realized by the time of flight measurement principle based on a green laser at 532 nm. The scanning range of the system allows distance measurements between 2 and 200 m. The scanner's spot size is 3 mm at a distance of 100 m; the standard deviation of the distance measurement is 6 mm for a single shot. The laser scanning system is able to measure 5,000 points per second. During data collection, a calibrated video snapshot of 768 ×576 pixel resolution is additionally captured, which is automatically mapped to the corresponding point measurements. Table 1 shows the Ground-based LiDAR parameters of this study.

Table 1 The Ground-based LiDAR parameters of this study

Item	LiDAR Information
Speed	up to 5000 pts/s
	532nm
Field of View	360°×60° (in one site)
Camera	768×576 pixel resolution
Vertical Resolution	100 mm at 100 m
Horizontal Resolution	100 mm at 100 m
Area	20 m × 30 m
Point Clouds Information	X, Y, Z, I, R, G, B
Point Clouds Numbers	74.5 point m^{-3}

2.2 Field tests

The Ground-based LiDAR was used to characterize the plantation of *Chamaecyparis formosana* (Fig.1) at Lukuei Area in Taiwan.

Fig. 1 The plantation of formosan red cypress (*Chamaecyparis formosana*) at Lukuei Area in Taiwan

2.3 LiDAR measurements

The Ground-based LiDAR was optical sensor, so has some problem in shooting process. Fig. 2 shows this problem and defines the three types of occlusion problem as they are known in computer graphics applications: ambient, self and view frustum occlusions.

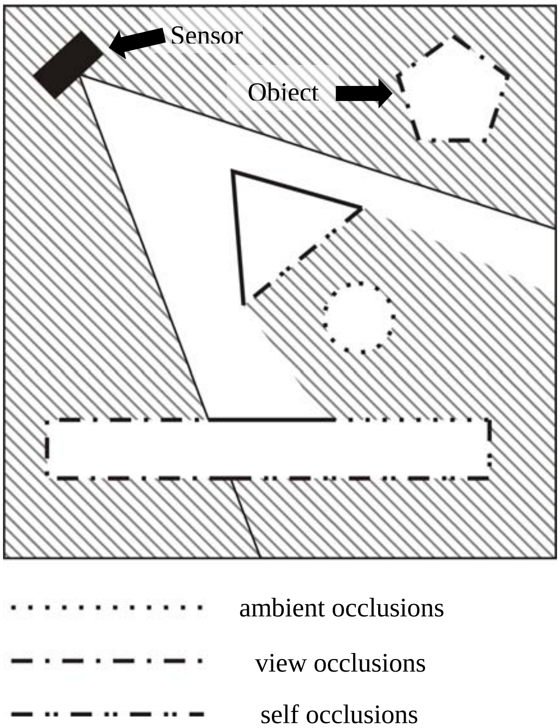

Fig. 2 Visibility occlusions and double projection problem

These systems can record the configuration of whole plants and forest structures as a 3D point clouds image by merging LiDAR data measured from different positions (Fig. 3). In Fig. 3, the registration is a process that calculates point clouds from different positions, which is calculating relative positions that make the gap between configuration common parts close to zero theoretically. The procedure that was coordinate conversion of point clouds form the same coordinate system, and it is determined by movement and rotation elements in 3D space. The point clouds have formed the same coordinate system through registration are converted to targets absolute coordinate merging with control points by georeferencing.

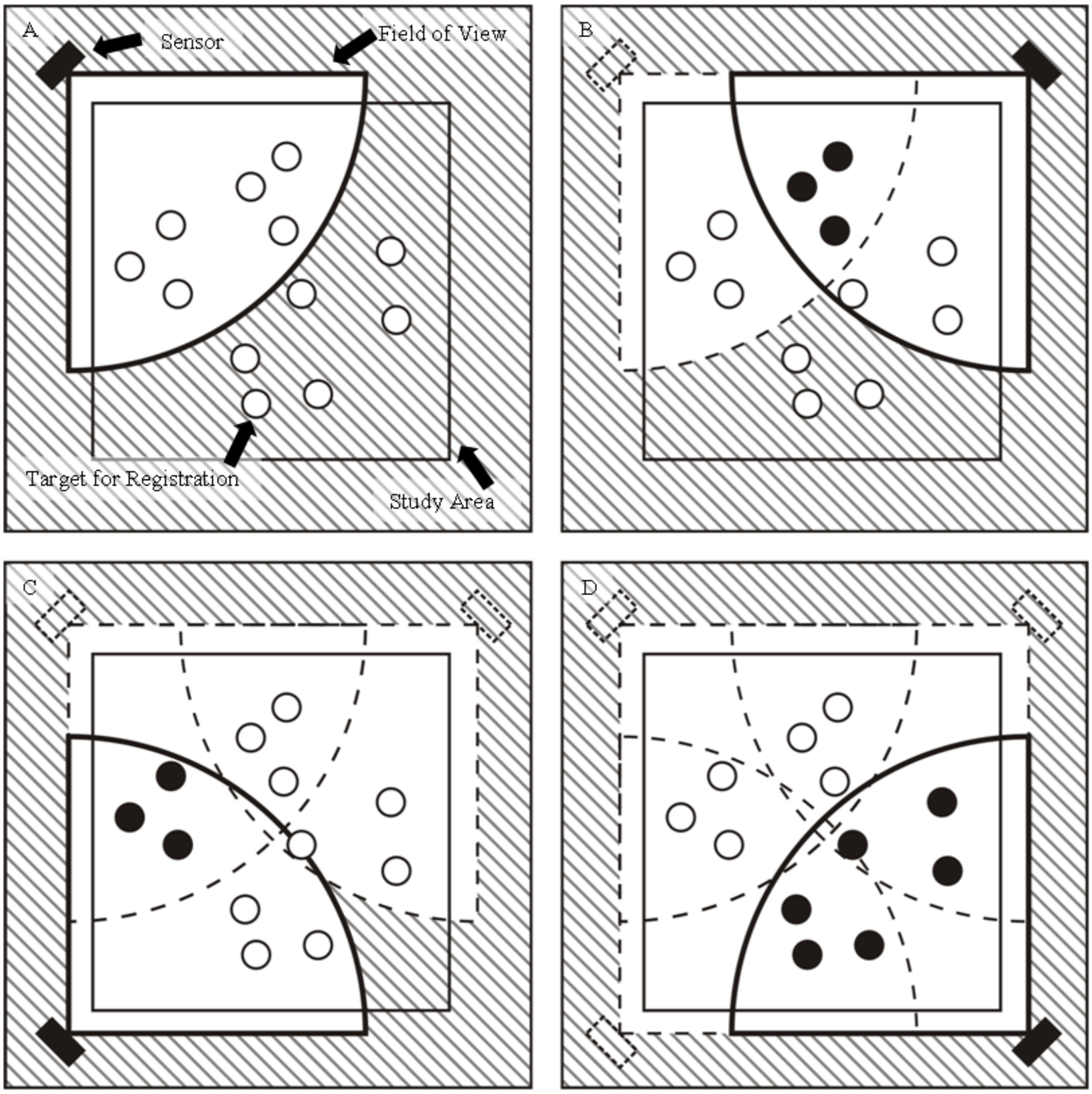

Fig. 3 Principle of registering point clouds measured from different locations and georeferencing point clouds passed through a registration process

2.4 Manual measurements of tree height, diameter at breast height, and individual tree location map

Comparing with the LiDAR results, the height, DBH, and location of trees were measured manually. Firstly, several representative trees were chosen. The measurement of the volume of a tree began with the measurement, the maximum tree height and the height of the bare trunk in a plane perpendicular to the row containing the trunk axis. As a critical element for georeferencing, control survey is a procedure that requires extremely close observation. A Sokkia SET530RK3 reflectorless total station was used for field survey and this equipment has the range measurement accuracy of ± (2mm+2ppm × D) in prism mode and ± (3mm+2ppm) in reflectorless mode (Sokkia 2006). LiDAR measurements of tree height, DBH, and individual tree location map were based on point measurement (Fig. 4). The 24 trees were also observed to analyze the accuracy of finally processed in 3D information.

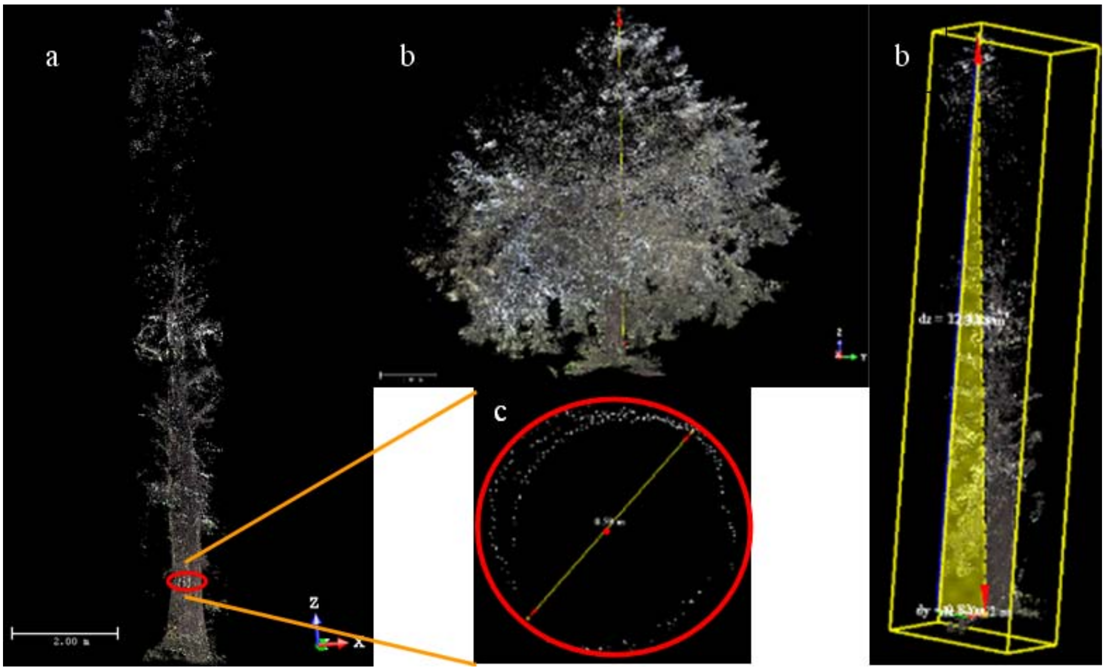

Fig. 4 Using LiDAR data to extract stumpage (a) ; LiDAR data (red point) to measure tree height and individual tree location (b) ; LiDAR data to measure diameter at breast height (c)

3. RESULTS AND DISCUSSION

Based on the relationship between the LiDAR measured tree height, DBH and the respective in measured manually. So far as tree height and DBH were concerned, manually determined and LiDAR obtained results were not identical but a simple relationship existed between the values as is shown in Fig. 5 and Fig. 6.

In Fig. 5, the case of tree height, there exists a simple relationship between both values. In Fig. 6, the relationship between DBH of each tree and the respective calculated from LiDAR DBH is shown. In spite of the heterogeneity of the trees, there is a good correlation between the LiDAR tree height and field tree height (coefficient of determination R^2=0.8644, RMSE=0.2584) or the LiDAR DBH and field DBH (coefficient of determination R^2=0.9685, RMSE=0.7632).

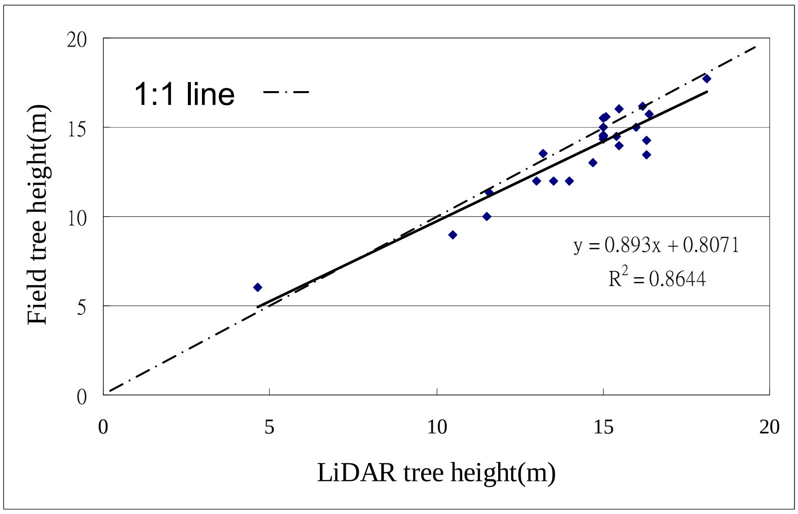

Fig. 5 Correlation between field tree height (y) and LiDAR measured tree height (x); the regression formula obtained was y = 0.893x + 0.8071

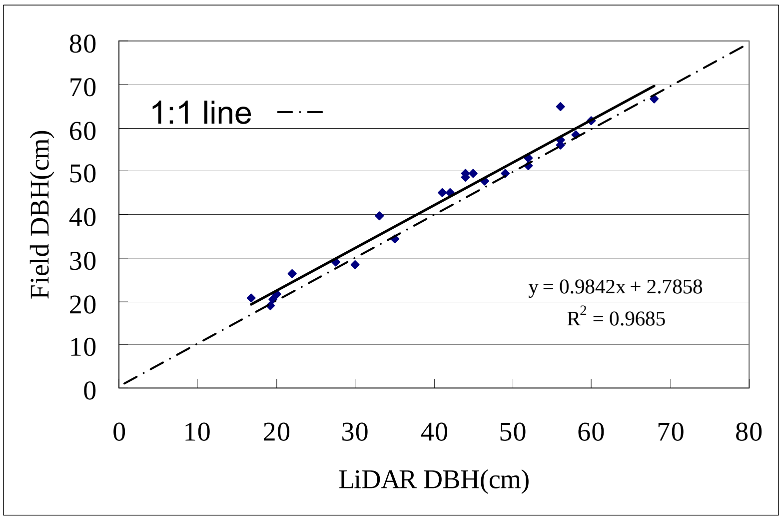

Fig. 6 Correlation between field DBH (y) and LiDAR measured DBH (x); the regression formula obtained was y = 0.9842x ＋ 2.7858

The Fig. 6 shows correlation between LiDAR measured DBH and field DBH, and it is accepted as almost the same value visibility occlusion and double projection problem errors.

The point clouds rotation and moves in 3D spaces through registration and georeferencing. To analyze the accuracy of ultimately determined 3D information, the result of 24 trees by field survey was compared to that of laser scanning. As the results, directional errors are indicated as Fig. 7, 0.020-0.796 m in direction X and 0.007-1.774 m in direction Y. Compared to the results from traditional methods, these values show the developments of new method of survey and practical applications in various measurement fields are highly expected.

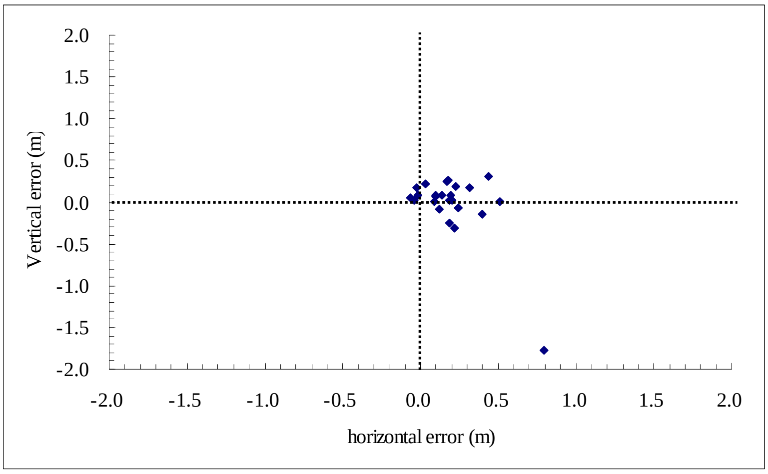

Fig. 7 Accuracy of LiDAR data, vertical error (m) (y) horizontal error (m) (x)

Polo *et al*. (2009) use a low-cost tractor-mounted scanning Light Detection and Ranging system (ground-based LiDAR) for capable of making non-destructive recordings of tree-row structure in orchards and vineyards were describe. The results for apple and pear orchards and a wine producing vineyard were shown to be in reasonable agreement with the results derived from a destructive leaf sampling method. Therefore, good correlation was found between manual and sensor-based measurements of the vegetative volume of tree-row plantations. The Tree Area Index (TAI) parameter, gave the best correlation between destructive and non-destructive (i.e. LIDAR-based) determinants of crop leaf area. The LiDAR system proved to be a powerful technique for low cost, prompt and non-destructive estimates of the volume and leaf-area characteristics of plants.

Keightley and Bawden (2010) use tripod LiDAR (ground-based LiDAR) to establish 3D volumetric modeling of grapevine biomass. LiDAR analog volume is shown to have a high correlation with mass that is modeled by a simple linear equation. This laser scanning technique yields a highly linear relationship between vine volume and tissue mass revealing a new, rapid and non-destructive method to remotely measure standing biomass. This application shows promise for use in other ecosystems such as orchards and forests.

4. CONCLUSIONS

In this study, the LiDAR-based had proved to be a valuable tool for the measurement of the tree height, DBH, and individual tree location map. Depending on the needs of a study, measures could be taken as frequently as needed without injury to the trees. In the research, tree height, DBH, and individual tree location map were accessed by measuring 3D point clouds which varies depending on the technique used. Measures by LiDAR data is shown to have a close correlation with field data that is modeled by a simple linear equation. The strengths of the LiDAR technique are rapid, accurate numerical value measurements with as few as four instrument views per tree, not necessary for destructive harvest. Limitations of this technique are the availability of instrumentation and software, loss of accuracy at the finest target scales and errors introduced. Application of this technique in the field requires multiple repositioning of the instrument for each one which can increase the time required to collect data, however no difference in data accuracy is anticipated.

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