# THE EFFECTS OF FOOTPRINT SIZE AND SAMPLING DENSITY IN AIRBORNE LASER SCANNING TO EXTRACT INDIVIDUAL TREES IN MOUNTAINOUS TERRAIN

Y. Hirata

Shikoku Research Center, Forestry and Forest Products Research Institute, Asakura-Nishi, Kochi, 780-8077, Japan - hirat09@affrc.go.jp

**KEY WORDS:** airborne laser scanner, footprint size, sampling density, individual tree height, digital elevation model, digital surface model, digital canopy model

**ABSTRACT:**

The effects of footprint size and sampling density in airborne laser scanning on extraction of individual trees in a mountainous terrain were investigated. A stand of Japanese cedar was selected for the study. Three flight altitudes of the helicopter above the ground, 300, 600 and 1,200 meters, were used to acquire the data with different footprint sizes. The footprint diameters were approximately 0.3, 0.6 and 1.2 meters respectively. Sampling densities corresponding to three flight altitudes were 24.8, 10.1 and 7.5 points/m$^2$. DCM (digital canopy model) for each altitude with 1-meter was generated from three measurements and they were compared to understand the effects of footprint size. Quasi-data of 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 of sampling density were created from the original first and last pulse data acquired from the measurement at a flight altitude of 300 meters. Individual trees that were extracted from these data were examined in terms of the position and the value of tree height to evaluate the sampling density. The mean values of subtraction of DCM by footprint size of 0.3 meter from DCM by footprint size of 0.6 meter and 1.2 meters were 0.5 meter and 0.9 meter respectively. The rate of extraction of treetops from DCM declined suddenly in case the sampling density was below 3 - 5 points/m$^2$. The difference between mean tree height derived from DCM with high sampling density and one with low sampling density was 0.5 - 0.6 meters and the height with low sampling density was underestimated.

## 1. INTRODUCTION

Remote sensing techniques are suitable to observe ground surface widely and many methods for understanding forest condition and evaluating forest function with them have been proposed. Therefore, it is expected that they play an important role in monitoring of forest, measurement of carbon sink and so on. On the other hand, conventional remote sensing has a limitation for acquisition of stand information because of mostly two-dimensional information.

Lidar (<u>li</u>ght <u>d</u>etection <u>a</u>nd <u>r</u>anging) remote sensing is an expansion from two-dimensional observation to three-dimensional measurement and we expect to improve its accuracy to estimate the potential of productivity and biomass through the acquisition of three-dimensional data. Its application for forestry started from 1980s (Maclean and Krabill, 1986; Nelson et al., 1988) and there has been growing interest in the utilization of lidar remote sensing in forestry. Pervious studies showed that stand parameters such as tree height (Nelson, 1997; Næsset, 1997a; Magunussen and Boudewyn, 1998; Magunussen et al., 1999; Næsset and Bejerknes, 2001; Næsset and Økland, 2002), number of stems, and stand volume (Næsset, 1997b; Means et al., 2000; Lefsky et al., 2001) could be estimated from airborne laser scanner data accurately. Recently, individual tree attributes and canopy structure have been derived from airborne laser scanner data with high sampling density (Hyyppä et al. 2001; Persson et al. 2002; Brandtberg et al. 2003; Hirata et al, 2003). It has been also applied to ecological studies (Hinsley at al., 2002; Lefsky et al., 2002).

Though the increase of interests for the utilization, the footprint size and the sampling density have not been examined sufficiently. The footprint size of airborne laser scanner influences the generation of DEM (digital elevation model) particularly in a mountainous terrain because an elevation at a centre of footprint is normally higher than an elevation obtained from the last pulse because of its topographical properties. As a result, individual tree heights are more overestimated in case of larger footprint. The size also effects on the generation of DSM (digital surface model). The sampling density is very important not only for the recovery of individual tree crowns in detail but also for the generation of accurate DEM. In the study, the effects of footprint size and sampling density of airborne laser scanning to extract individual trees in a mountainous terrain were investigated.

## 2. MATERIALS AND METHODS

### 2.1 Study Plot

The study plot is located in a national forest managed by the Ibaraki District Forest Office at the eastern part of Japan. A stand of Japanese cedar was selected for the study. The size of study plot was 1 ha and the stand density was 657 trees/ha at the moment of airborne laser scanner data acquisition. The plot was established for the experiment of thinning effect and it was divided to six quadrats. Every two quadrats were assigned to heavy thinning (every 0.15 ha), light thinning (every 0.2 ha) and no-thinning (every 0.15 ha) respectively. All tree heights were measured with VERTEX III (Haglöf, Sweden) and 4 corners of the plot were positioned by DGPS with Pathfinder (Trimble, U.S.A). All tree positions were measured and tree disposition map was created. It was converted to digital data on GIS to verify results from airborne laser scanner data.

### 2.2 Airborne laser scanner data

The ALMAPS (Asahi Laser Mapping System, Aero-Asahi Co., Tokyo, Japan), which consists of the ALTM 1025A / 1225 laser scanning system (Optech, Canada), the GPS airborne and ground receivers, and the inertial measurement unit (IMU) reporting the helicopter's roll, pitch and heading, was used to acquire the airborne laser scanner data. The laser scanner system transmits the laser pulse at 1,064 nm (near-infrared) and receives the first and last echoes of each pulse. The elapsed time between transmission and reception is measured to calculate the distance between the system and the object. The position of the helicopter and the scan angle are calculated helicopter with high accuracy using Kinematic GPS and IMU after the flight.

The laser scanner data were acquired on 12 April 2001 and 18 April 2003. A helicopter was used as platform to get high sampling density data. Three flight altitudes were used to get data with different footprint sizes. The flight altitudes of the helicopter above the ground were 300 meters, 600 meters and 1,200 meters and the average of the flight speed was approximately 14 m/sec. The beam divergence was 1.0 mrad. Therefore, the footprint diameters were approximately 0.3 meter, 0.6 meter and 1.2 meters respectively. The pulse repetition frequency was 25 kHz and the scan frequency was 34 Hz. Maximum scan angle (off nadir) was 10 degrees. Overlap of scanning between neighbouring flight lines was about 50 %. Sampling density of the data on 12 April 2001 was 22.5 points/$m^2$ and sampling densities of the data acquired on 18 April 2003 corresponding to three flight altitudes were 24.8 points/$m^2$, 10.1 points/$m^2$ and 7.5 points/$m^2$ respectively. Both first and last pulse data were acquired to reconstruct forest canopy structure and topography.

### 2.3 Extracting individual trees and tree heights

Post-processing for the airborne laser scanner data was performed to correct aberration. DSM and DEM with 0.25-meter mesh size were generated from the first and last pulse data selecting maximum value and minimum value within each mesh respectively. DCM (digital canopy model) with 0.25-meter mesh size was calculated subtracting the DEM from the DSM. Local maximum meshes were extracted as treetops from the DCM using a local maximum filter. Treetops derived from the DCM were confirmed and identified using digital data of tree disposition on GIS.

Rates of extractive individual trees against standing trees in different operations such as heavy thinning, light thinning and no thinning were investigated by comparing between standing trees in the field and the number of treetops that were extracted from the DCM. The individual tree heights derived from the field measurement were regressed against ones derived from the DCM.

### 2.4 Comparing DCMs of different footprint sizes

DSMs and DEMs with one-meter mesh size were generated from first and last pulse data by three measurements of different flight altitudes selecting maximum value and minimum value within each mesh respectively and filtering out noise values. DCMs for every flight altitudes were calculated from the differences between corresponding DSM and DEM. DCM derived from the data by footprint size of 0.3 meter was subtracted from DCMs derived from the data by footprint sizes of 0.6 meter and 1.2 meters respectively and the differences were investigated to evaluate the effect of footprint size on extraction of individual trees from airborne laser scanner data.

### 2.5 Effect of sampling density

Quasi-data of 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 of sampling density for original first pulse data acquired from the measurement at a flight altitude of 300 meters were created systematically. Three DEMs with different mesh sizes, 0.25 meter, 0.5 meter and 1 meter was generated from the original last pulse data of the same flight altitude. DSMs with the different mesh sizes were generated from the original first pulse data and the quasi-data set of different sampling density respectively. DCM for each mesh size and each sampling density was calculated by subtracting DEM with equivalent mesh size from DSM with corresponding mesh size and sampling density.

Next, the number of extractive standing trees from each DCM with the local maximum filter was investigated. When the sampling density of laser beams decreases, the probability that footprints involve treetops becomes small and the value of a position nearby treetop, which laser beam hits, is regarded as tree height. As a result, tree heights derived from airborne laser scanner data are underestimated. Tree heights concerning extractive standing trees from DCMs derived from different sampling densities were compared.

## 3. RESULTS AND DISCUSSION

Table 1 shows the numbers of standing trees and extractive trees from DCM with 0.25-meter mesh size, and rates of extractive individual trees against standing trees in different thinning operations such as heavy thinning, light thinning, and no thinning. Trees that could not be extracted in the analysis were suppressed trees or trees that lacked their tops because of strong wind. These trees were found mainly in quadrats of no thinning and the rate of number of trees which could not extracted there against number of trees which could not extracted in the plot was 63.2 %.

Table 1. The numbers of standing trees and extractive trees, and rates of extractive individual trees against standing trees in different thinning operations

| thinning operation | number of standing trees | number of extractive trees | extractive rate (%) |
|---|---|---|---|
| heavy (0.3 ha) | 142 | 136 | 95.8 |
| light (0.4 ha) | 245 | 212 | 86.5 |
| no (0.3 ha) | 270 | 203 | 75.2 |
| total (1.0 ha) | 657 | 551 | 83.9 |

Estimated individual tree height ($H_l$) was plotted against individual tree height in field measurement ($H_f$) for 551 extractive trees (Figure 1). The line fitted to the data with the least-squares methods was as follows.

$$H_f = 1.009H_l - 0.59$$

As a result, individual tree heights derived from airborne laser scanner data were slightly overestimated against ones from field measurement. The correlation coefficient between tree height derived from airborne laser scanner data and one from field measurement was 0.92.

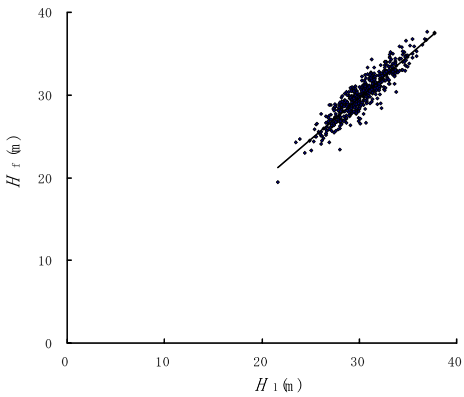



Figure 1. Estimated individual tree height plotted against individual tree height in field measurement for 551 extractive trees

The differences between estimated individual tree height and tree height in field measurement are considered to occur from some factors concerning the field measurement, the airborne laser scanner data, and the definition of tree height. Instrumental errors in measurement and errors by observer are given as the factor of field measurement. The errors of airborne laser scanner data occur at the moment of the measurement and in the post-processing. It is reported that the error is not more than 0.2 meter. Tree height derived from airborne laser scanner data is calculated as the difference between DSM and DEM at the treetop position. As a result, a tree height derived from airborne scanner data is underestimated in case the tree leans towards upper side of slope and one is overestimated in case the tree leans toward lower side of slope (Figure 2). Comparison between positions of tops of trees derived from DCM and their root positions from digital tree disposition data on GIS have shown what about 70 % of standing trees lean toward lower side of slope and the mean difference between DEM at the root position and DEM at the treetop position was about 0.2 meter.

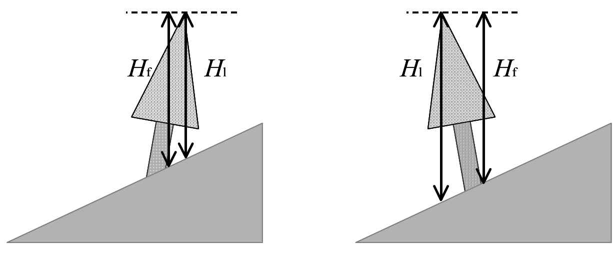
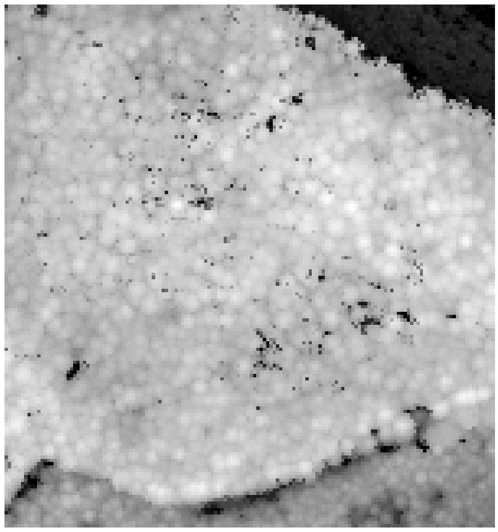
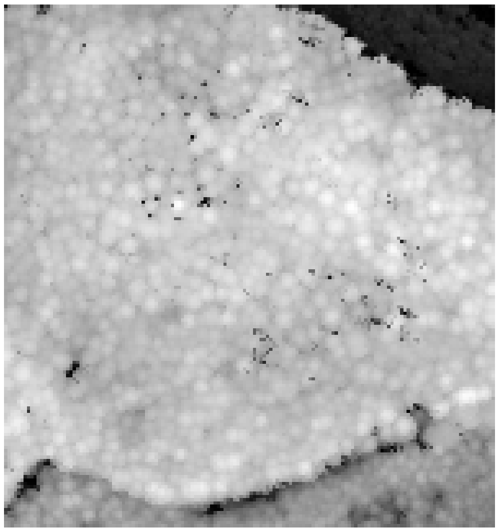



Figure 2. Factors of underestimation and overestimation of tree height in mountainous terrain

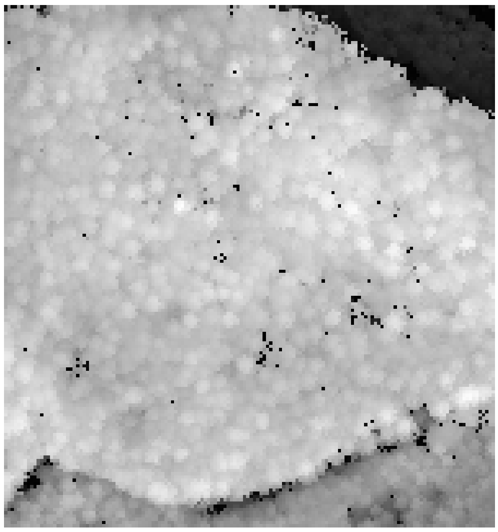
Three DCMs with 1 meter mesh size derived from footprint sizes of 0.3 meter, 0.6 meter and 1.2 meters appear in Figure 3. Smaller size canopy could be distinguished in the DCM derived from smaller footprint.



(a) footprint size = 0.3 meter



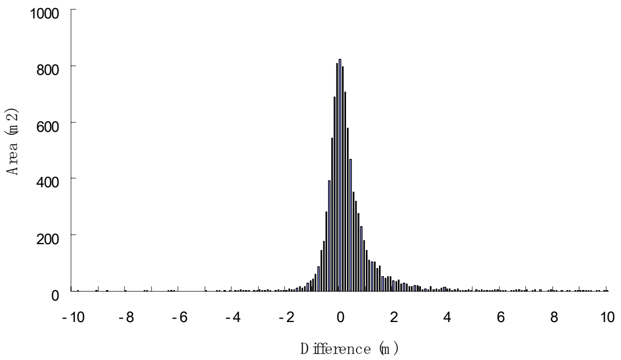
(b) footprint size = 0.6 meter



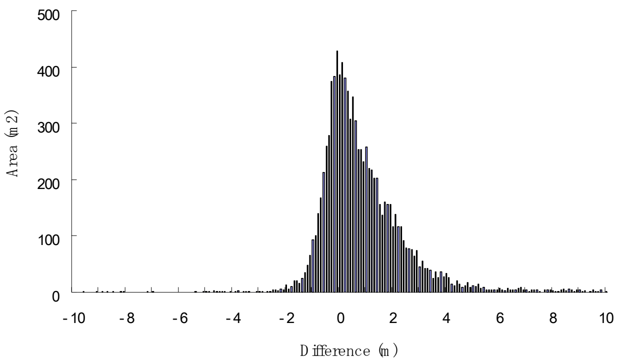
(c) footprint size = 1.2 meters

Figure 3. DCMs derived from different footprint sizes

Figure 4 illustrated histograms of subtraction of DCM by footprint size of 0.3 meter from DCM by footprint size of 0.6 meter and 1.2 meters. The mean values of differences were 0.5 meter and 0.9 meter respectively. These results made it clear that canopy surface height in DCM by larger footprint is overestimated in comparison with the height in DCM by smaller footprint.



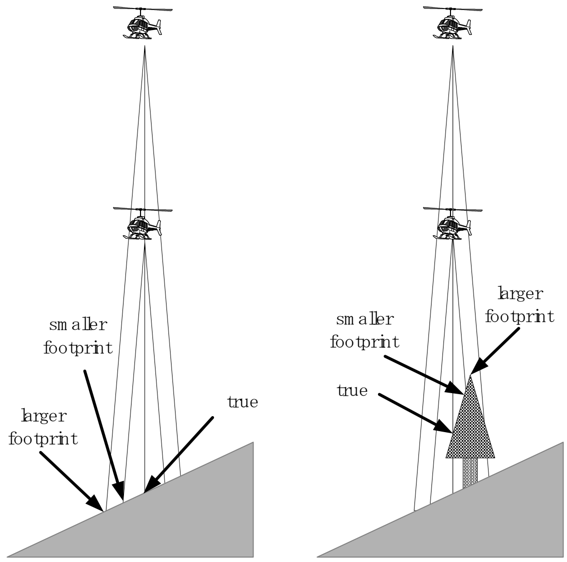

(a) Subtraction of DCM by footprint size of 0.3 meter from DCM by footprint size of 0.6 meter




(b) Subtraction of DCM by footprint size of 0.3 meter from DCM by footprint size of 1.2 meters

Figure 4. Histograms of subtraction of DCM by footprint size of 0.3 meter from DCM by footprint size of 0.6 meter and 1.2 meters

In mountainous terrain, footprint size of laser beam effects on generation of DEM. Last echo of each pulse reflects from lower position in comparison with the altitude of centre of footprint. As a result, DEM derived from the last pulse data is underestimated and consequently DCM is overestimated. If the footprint is large, the underestimation of DEM also becomes large (Figure 5 (a)). Smaller footprint leads underestimation of DSM in comparison with larger footprint in some cases because it is sometimes possible for larger footprint to involve higher area of canopy. In the case, DSM is overestimated for the altitude of canopy surface at the centre position of footprint (Figure 5 (b)). When sampling density is quite high and neighbouring footprints are overlaid, the effect of footprint size on extraction of tree height is small because some footprints involve whole treetops in canopy surface. It follows from what DCM by larger footprint was overestimated for DCM by small footprint in mountainous terrain.




(a) DEM (b) DSM

Figure 5. Measuring points as altitude in DEM and DSM with different footprint sizes in mountainous terrain

Quasi-data of 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 of sampling density for original first pulse data acquired from the measurement at a flight altitude of 300 meters had sampling densities of 11.3, 5.6, 2.8, 1.4, 0.7 and 0.4 points/m$^2$ respectively. Figure 6 shows the relationship between sampling density of laser beams and number of extractive trees for each mesh size. In case of the sampling density of more than 5 points/m$^2$, the rate of extractive trees with 1 meter and 0.5 meter mesh sizes against 0.25 meter mesh size were about 60 % and 90 % respectively. The rate of extraction of treetops from DCM declined suddenly in case the sampling density was below 3 - 5 points/m$^2$.

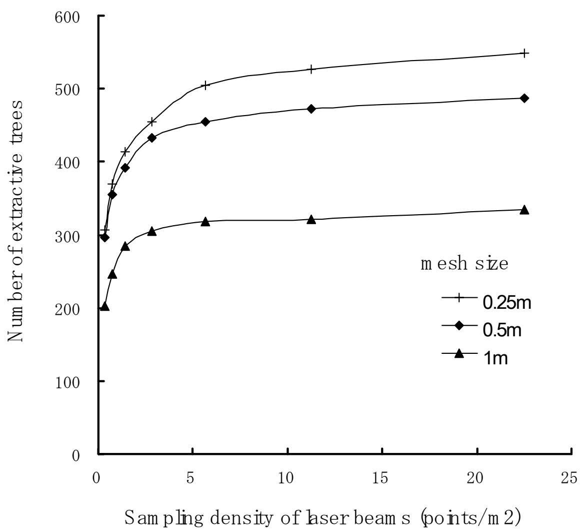



Figure 6. The relationship between sampling density of laser beams and number of extractive trees from airborne laser scanner data

Sampling density of laser beams is considered to effect on the estimation of individual height. The relationship between sampling density of laser beams and number of extractive trees for each mesh size was represented in Figure 7. Because smaller size trees could be extracted from the DCM with 0.25-meter mesh size, the mean tree height in the same sampling density is smallest for the 0.25-meter mesh size. The difference between mean tree height derived from DCM with high sampling density and one with low sampling density was 0.5 - 0.6 meters and the estimated height with low sampling density was underestimated.

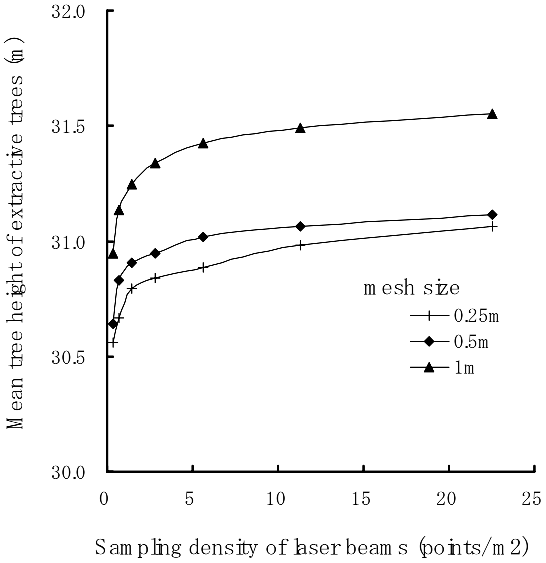



Figure 7. The relationship between sampling density of laser beams and mean height of extractive trees in each mesh size

## 4. CONCLUSIONS

The current study made clear the effects of footprint size and sampling density of laser beams in forest measurement using airborne laser scanner data on the extraction of individual trees in a mountainous terrain. Footprint size and sampling density are decided by the measurement parameters such as flight altitude, flight speed, scanning angle, and so on. We should select suitable measurement parameters for target forest stand. In Japan, forests grow up in mountainous area and forest patch is relatively small. Therefore, suitable measurement parameters to acquire airborne laser scanner data for each forest should be investigated.

Lidar remote sensing is expected to become a tool for forest inventory. Nevertheless, there are some problems that should be solved for practical uses. Acquisition of advance information for the target of forest inventory from GIS data concerning stand attributes is essential to reduce the cost of airborne laser scanning measurement and to select suitable measurement parameters beforehand.

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