PRACTICAL APPLICATION FOR ESTIMATING THE CROWN DENSITY OF CONIFERS USING LIDAR DATA

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ABSTRACT:

The crown density is related with the hierarchical structure of the trees and one of the most important factors considering the biological diversity. This study focuses on the advantage of the LiDAR data, and we tried to estimate the crown density of conifers using the 3-dimensional distribution of the LiDAR pulses. The targets were selected from 13 areas of Hinoki and 10 areas of Cedar tree species in Izu region, Japan. The reference data was acquired by the interpretation of high-resolution optical airborne data inside 15m radius area. The gap rate was estimated by the ratio between 1st pulse reflected by the forest floor and others by plot area, and acquired crown density was compared with the reference one. The analyzed results showed that a highly positive correlation was found between them. In addition to the rate of crown density, a relative spacing was utilized, and the correlation coefficient affected the threshold of the forest floor. This study shows the potentiality of the LiDAR data for the estimation of the crown density of the conifers. The examination of the application to other tree species is necessary for the future studies.

1. INTRODUCTION

Airborne LiDAR is one of the effective tools to grasp the forest in a 3-D format over large area. Full waveform-digitizing, large footprint LiDAR provides highly accurate measurements of forest structure at the footprint level of observation in the recent years though the separation of LiDAR points into terrain and ground hits still remains a task. This technology has been widely applicable for the topographic relief (Krabill *et a*l., 1984), forest biomass (Hyyppa *et al*., 2001; Nasset, 1997), individual tree canopy height (Brandtberg *et al*., 2003; Popescu *et al*., 2002), etc. In addition to ground topography, LiDAR data gives new information about the canopy surface, such as stem density, and crown dimension (Lefsky *et al*., 1999).

Measurements of the tree structure are critical for several applications, including biodiversity study, and wildlife management. The crown density is one of the key parameters to describe the state of the forest trees. This study examines the crown density, defined as a ration of the forest tree crown to the total forest area.

In the previous studies, optical airborne data were utilized and binarized value of the reflectance was analyzed for the estimation of the crown density, but the forest floors were also misclassified as tree crown coverage. Moreover, it is also necessary to adjust the threshold value depending on the shade of the forest types, therefore the methodology used to be unsatisfactory for the practical usages.

On the contrary, the LiDAR pulse measurements lead for the possibility to grasp the structure inside the forest visually and instinctively. This study focuses on the kinds of pulse and its distribution, and we tried to estimate the crown density of conifers (Hinoki and Cedars) and using the 3-dimensional distribution of the LiDAR pulses.

2. UTILIZED DATA

2.1 Study Site

The study area is Yugashima, Izu region in Japan and includes the national forest. Figure 1 shows the map (5km by 5km) covered to acquire the LiDAR data. The area is southern slope of Mt. Amagi, and the height ranges from 350 m to 1300 m.

The lava terrace, caused by the eruption about 3000 years ago, is spread in the western slope. In the Broadleaf trees, such as a beech, are grown in the mountain ridge, and the man-made forests, like Hinoki and Cedar, are dominant in the middle to the foot of the mountain.

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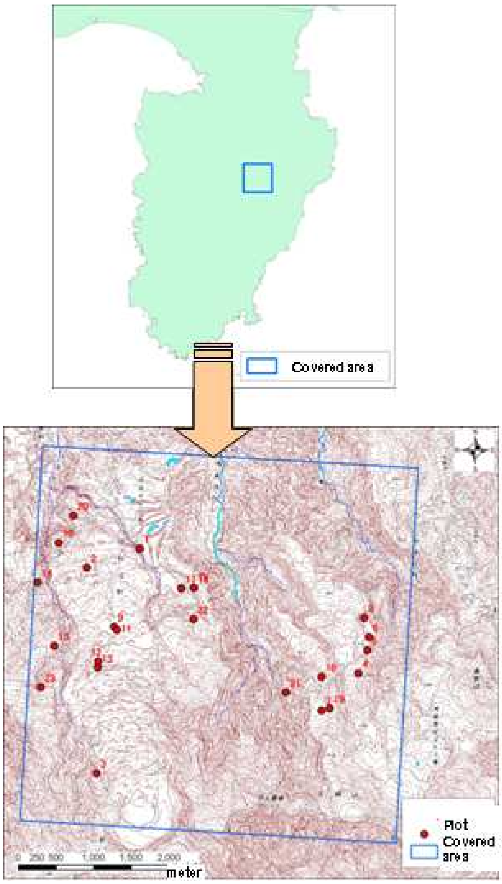


Figure 1. Map of Izu region acquired by the LiDAR data

2.2 LiDAR Data

The LiDAR data were acquired by Leica ALS50-II Airborne Laser Scanner, compact laser-based system designed for the acquisition of topographical and return signal intensity data. It allows accurate data collection independent of pulse rate, depending instead only on flying height. The flying height envelope ranges from helicopter-compatible 200m AGL to 6000m AGL for wide area mapping. Additionally, low noise laser pulses deliver outstanding accuracy, even at 150kHz pulse rates (Table 1).

The data is computed using laser range and return signal intensity measurements recorded in-flight along with position and attitude data derived from airborne GPS and inertial subsystems. It gives the vertical accuracy in the 15cm range and horizontal accuracy better than 1m.

Table 1 shows the specification of the airborne data. The LiDAR data were acquired for 4 days from 7 to 17 December, 2007. It flew aboard the AS350B helicopter at an average altitude of about 900m above the ground level. The airspeed was about 50knots. The ground cross sectional diameter (footprint) of the laser beam was approximately 0.2m. The laser instrument field of view and average flying height resulted in the average ground swath width of 482m. The entire study area was covered by 21 parallel flight lines, oriented east to west. The mission was designed with up to 50% sidelap between adjacent swaths to increase the point density on the ground. Up to four echoes are recorded for each laser pulse. The data include an (x, y, z) –position of each echo, and reflectance value.

Acquisition Date	December 7 (3 courses), 9 (9 courses), 14 (9 courses) and 21 (supplemental observation) in 2007
Platform	AS350B
Above Ground Altitude	900m
Ground Speed	50knots
Field of View	30deg (±15deg)
Pulse Rate	90,000Hz
Scan Rate	47Hz
Swath Width	482m
Number of Course	21
Sidelap	50%
Footprint	0.2m
Maximum point distance for along-direction	0.65m
Maximum point distance for range direction	0.65m

Table 1. The specification of the data acquisition

3. METHODOLOGY

Laser pulses from a sensor carried aboard an aircraft are directed toward the ground to collect ranging data to the top of the canopy, and in some instances, to subcanopy layers of vegetation and to the ground. Latitude, longitude, and the elevation of points on the grounds were measured from aircraft' position and orientation, scan angle, and round-trip propagation time of laser pulse.

3.1 Crown Density Estimation Method

Multiple return pulses are generated as the laser pulse hits various levels in the forest canopy, creating in total a complete return waveform. Figure 2 shows the sketch of multiple-return pulses for the forest canopy. Most of the first return is considered to be from the top of the tree crown, and the second pulse from branches, and third one from ground. In case of any gap between the canopies, first and only single return is from the ground.

Therefore, the crown density is estimated by the ratio of first pulse returned from the upper layer of tree crown to the all transmitted first pulse to the forest canopy, while the gap rate is by the ratio of first pulse from the forest floor to the all pulse. This study utilizes the following equation to estimate the crown density.

Crown density = 1-(Number of first pulse from forest floor)/(Number of first pulse) (1)

Estimation accuracy was examined by varying the threshold of the forest floor.

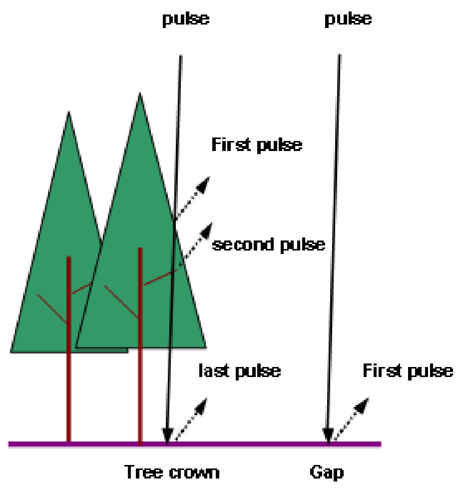


Figure 2. Multiple pulse return for the forest canopy

3.2 Ground Reference Data

The ground-truth data collection took place in the December 2007, almost same time of the LiDAR observation. Table 2 shows the summary of 23 plots examined in this study. It includes the two forest species of Hinoki (13 plots) and Cedars (10 plots). The stand age varies from 9 years for the young Hinoki to 114 years for old Cedars. One plot is distributed over an area of approximately 0.070 ha each with a radius of 15 m, thus it represents a sample of condition within this area. To allow a more detailed inventory of trees within the plots, we measured the height of all trees inside the plot using Vertex hypsometer. Height of upper layer was calculated from the average height of 20 % of upper layer (Munakata *et al.*, 2007). Crown density was determined by aerial photo using a point-grid plate.

No	Species	Age	Area (m^2)	Num -ber	Height of upper layer (m)	Crown density
1	Hinoki	40	706.5	114	16.3	98.0
2	Hinoki	33	706.5	93	14.1	97.9
3	Hinoki	29	706.5	27	15.2	77.8
4	Hinoki	66	706.5	52	19.0	85.4
5	Hinoki	27	706.5	31	12.4	81.6
6	Hinoki	27	706.5	59	13.8	97.7
7	Hinoki	65	706.5	39	16.5	91.9
8	Hinoki	27	706.5	78	12.1	97.9
9	Hinoki	16	706.5	163	12.6	90.6
10	Hinoki	18	706.5	71	13.1	90.8
11	Hinoki	16	78.5	32	5.7	97.5
12	Hinoki	23	153.4	37	11.0	81.8
13	Hinoki	9	706.5	40	6.5	95.3
14	Cedars	38	706.5	98	17.9	93.7
15	Cedars	50	706.5	107	19.6	97.5
16	Cedars	15	706.5	121	13.4	83.2
17	Cedars	53	706.5	28	21.1	86.5
18	Cedars	47	706.5	35	18.2	72.6
19	Cedars	64	706.5	23	24.8	75.5
20	Cedars	114	1256	41	34.2	91.5
21	Cedars	28	706.5	75	18.2	87.5
22	Cedras	40	706.5	49	14.7	63.4
23	Cedars	36	706.5	88	18.4	85..1

Table 2. The summary of the plot

4. RESULTS

4.1 LiDAR Data Analysis

Figure 3 shows the methodology adopted to analyze the LiDAR data. First, three elements (x, y, z) and exterior orientation elements were calculated from scan angle, distance, orientation angle of gyro, acceleration, and GPS information acquired by the LiDAR data. Then, the geometric accuracy, estimated by comparison between acquisition data and control point, indicating the both horizontal and vertical accuracy of 25 cm. The original data were generated by removing the error such as noise from the acquisition data. After that, DEM was extracted from the maximum value of the each grid cell. The grid cell size for the interpolated DEM is 0.5 m.

In the second stage, the first pulse was extracted from LiDAR data. Then, the threshold value was determined, and the finally the crown density was estimated from the equation (1).

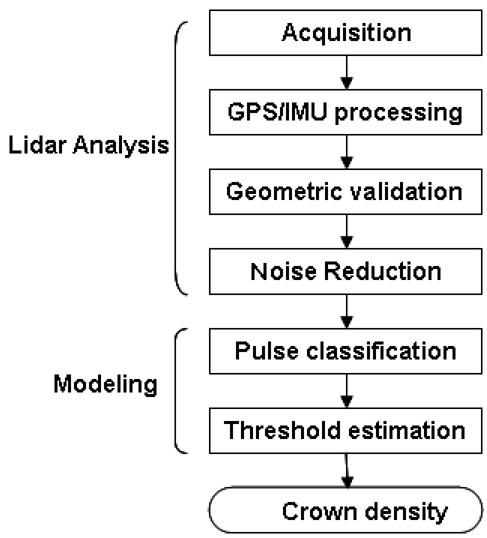
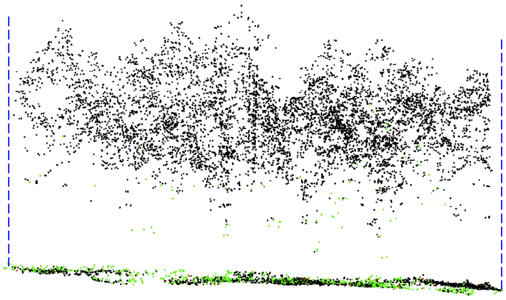


Figure 3. Flowchart of the crown density estimation algorithm

The distribution of the LiDAR pulse of the Plot 3, Hinoki, and the aerial photo and the ground photo inside the forest are shown in Figure 4 and 5, respectively. From the aerial photo and the ground photo, a gap was noticed in the forest, and the pulse was able to penetrate the canopy. Most of the first pulse, shown in the black points, concentrates on the canopies, however they can be seen at the forest floor at the gap of the canopy.

(a) Side View



(b) Slant View

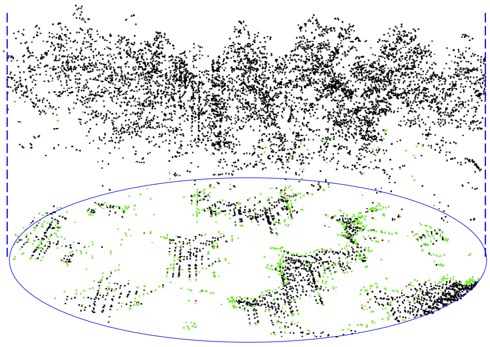
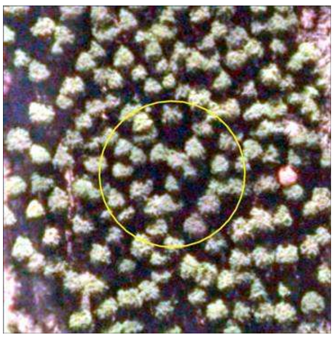


Figure 4. The distribution of the pulse of Plot 3, Hinoki (a) side view (a), and slant view (b)

(a)



(b)

Fig. 5. (a)Aerial photo, and (b) ground photo

4.2 Evaluation Result

The evaluation of this methodology was conducted by comparing the estimated crown density with the information derived from the interpretation of aerial photo.

The crown density was evaluated by the methodology as depicted LiDAR in Figure 3. The forest floor value was calculated from the multiple of the crown height (calculated from the DSM and DEM derived from LiDAR data) and the certain value (α, threshold). The result of α =0.1 is shown in Figure 6.

The significant positive correlation is found between estimation and observation, though the variation of the value is seen for the forest with high crown density. The correlation coefficients for Hinoki and Cedars are 0.80 and 0.91, respectively. RMS errors of the crown density is about 4.5 %, and it implies that the crown density can be estimated accurately focusing on the LiDAR first pulse.

Table 3 shows the correlation coefficients and RMS errors when the threshold (α) varies. The correlation coefficient is almost same when the threshold is less than 0.3, then it decreases when the threshold is more than 0.3. The best value is affected by the tree species and the structure of the trees. The determination of the threshold by the species is left for future studies.

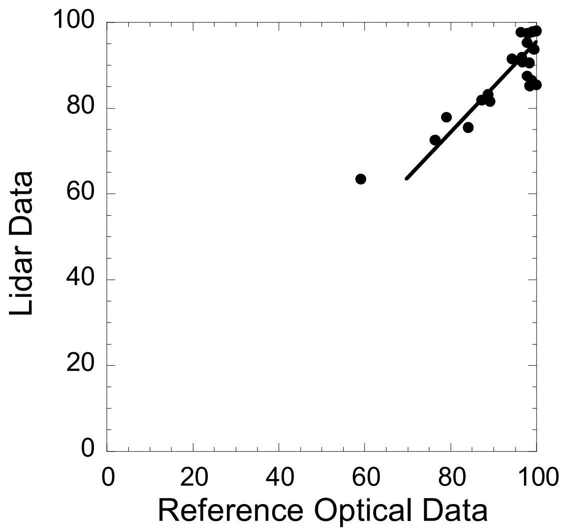


Figure 6. Comparison of the crown density between the estimation and observation

Threshold	Correlation Coefficient	Estimation Accuracy (%)
0.1	0.88	4.4
0.3	0.88	4.5
0.5	0.74	6.3
0.7	0.56	7.8
0.9	0.33	8.8

Table 3. Relationships between the threshold of the forest floor, the correlation coefficient, and the estimation accuracy for the crown density

In the next stage, other index, a relative spacing, showing the thinning of a forest was focused. Table 4 shows the relationships between the threshold of the forest floor and the correlation coefficient. The peak which shows the maximum correlation coefficient is different from that of the crown density. One of the reasons is that this index includes the forest height itself.

Threshold	Correlation Coefficient
0.1	-0.10
0.3	-0.17
0.5	-0.51
0.7	-0.61
0.9	-0.24

Table 4. Relationships between the threshold of the forest floor, the correlation coefficient for a relative spacing

5. CONCLUSIONS

This study focused on the advantages of the LiDAR data, and we tried to estimate the crown density of conifers using the 3-dimensional distribution of the LiDAR pulses. The targets were selected from 13 plots of Hinoki tree species and 10 plots of Cedars in Izu region, Japan. The crown density was estimated by the ratio between 1st pulse returned by upper layer and others by plot area, and acquired ratio was compared with the reference crown density.

The results showed that a highly positive correlation was found between the estimation and observation of the crown density. In addition to the rate of crown density, several parameters, such as relative spacing and a yield index are utilized as indices showing the crown density, and the validity of these parameters were confirmed. It is also variable to estimate these parameters by LiDAR data from the viewpoint of the biological diversity.

In order to grasp the forest structure, the acquisition of high-density LiDAR data is effective, while the balance is necessary between the cost and effectiveness. The three-dimensional acquisition of the structure inside the forest by LiDAR data, however, makes it possible to represent visually, and it is useful to widen the knowledge among the public.

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