Estimating Dense Forest Canopy Structure Using Airborne Laser Scanner Data

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Abstract: Returned laser pulse has certain relationship with vegetation canopy structure (canopy closure, height, LAI, biomass). This study attempts to analyze the characteristics of airborne laser scanner data over very dense forest canopy. Discrete pulse laser scanner data were obtained on April 25, 2004 along with digital aerial color imagery. Using forest stand maps, 14 sample stands of 7 species groups were selected and the elevations from the first and last laser return were compared. From the preliminary analysis, we found that the difference between the first and last return was higher with deciduous forest stand than in coniferous stand. Although difference between the first and the last laser returns often corresponds to tree height, it would not be the case for the forest site having very dense canopy structure.

Keywords: Lidar, forest, tree height, canopy closure.

1. Introduction

Laser altimeter is a simple form of active remote sensor that determines elevation by measuring the traveling time of a laser pulse [1]. Although the primary applications of airborne laser scanner data have been precise topographic mapping [2,3,4], there have been increasing numbers of applications other than topographic mapping. In recent years, airborne laser data have used various other applications, such as forestry, to survey and assess forest stand characteristics of tree height, canopy closure, biomass, and stand volume [5,6].

Most Lidar systems used in forestry are discrete return pulse laser system, which can record several vertical sampling for each transmitted laser pulse. The difference between the first and the last laser returns often corresponds to tree height. However, in dense canopy forest situation, it has been difficult to obtain the last return from the ground. For several study sites of forested environment, penetration rates of laser pulse were lower than 30% when the canopy closure is over 80% [7-10]. The objective of this study is to analyze the characteristics of airborne laser scanner data over very dense forest canopy situation. Since most forest lands in Korea have relatively dense canopy condition, the characteristics of laser return from forest are a important factor to derive any canopy characteristics as well as for the topographic mapping.

2. Methods

1) Study site and data acquisition

The study site, Mt. Oseo (791m elevation) is one of the tallest mountains in Chungnam province where the topography is relatively flat. As seen in Figure 1, the mountain is surrounded by agricultural cropland. Forest type in Mt. Oseo includes diverse species group of natural deciduous and coniferous, and plantation coniferrous stands.

Airborne lidar data was acquired using the Optech ALTM 30/70 system on April 25, 2004 (Table 1). The plane was flown at altitude of approximately 1,500m with total 15 flight lines. Data were obtained at 15 parallel flight lines with approximately 60% overlap between adjacent flight lines. The scan angle was ±20 degree from nadir, which provides approximately 1,100m swath width. With 0.2mrad of beam divergence of the lidar system, the laser footprint was about 30cm at 1,500m flying height. The ALTM 3070 is a discrete pulse laser system that can record the returned signal four-times for each transmitted pulse. Lidar system can record the 2-returned pulse information, but first and last pulse recorded at that time.

Table 1. Lidar specification of Optech ALTM 3070

Flying height	Horizontal accuracy	Elevation accuracy	Laser footprint	Pulse density	Repetition rate
1,500m	0.075m	< 25cm	30 cm	1.5 point/m^2	70kHz

During the Lidar data acquisition, digital color aerial images were also acquired by the same aircraft. Digital aerial camera (ALTM 4K02) has two-dimensional detector array of 4,092×4,079 pixels at three spectral bands of red, green, and blue wavelength. The camera's field of view (FOV) is 36 degree that gives us 30cm ground resolution. Digital color aerial images were ortho-rectified using the digital elevation model (DEM) data and used to select the sample plots.

Fig. 1. Distribution of 14 forest stands of known canopy structure within the study area of Mt. Oseu over Landsat TM image.

The forest stand map of Mt. Oseo area has produced by the Korea Forest Research Institute in 2003 using 1:15,000 scale aerial photographs. The map shows several stand parameters of species group, age, DBH and crown density. After the map was digitized and overlaid to the ortho-rectified aerial color images to select sample forest stands. Total 14 sample forest stands were selected to as compared with the laser scanning data (Figure 1). These sample stands are consisted of seven species groups of natural deciduous (H), mixed deciduous and coniferous (M), white pine plantation (PK), larch plantation (PL), pitch pine plantation (PR), natural oak (Q), natural Korean pine (D). All of these sample stands have relatively dense canopy closure (over 70%) and the average tree age is between 20 to 50 years old.

2) Extraction of Lidar data for sample forest stands

Airborne laser scanning data file shows the coordinates, elevation, and intensity of every returned laser pulses. Figure 2 shows the distribution of the center location of laser pulses a small portion of the dataset. The Lidar data are provided with two (first and last) returned pulses. From the raw Lidar data, we extracted the first and the last return data for each of the sample stands (Figure 3).

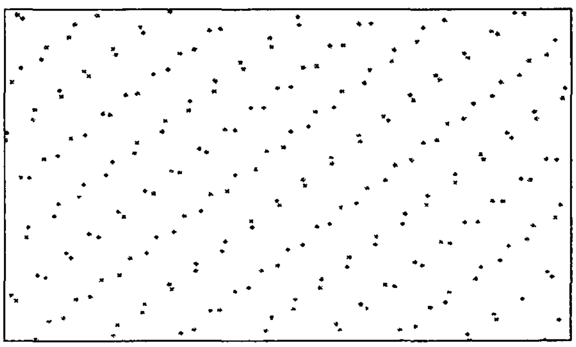

Fig. 2. Distribution of the center location of laser pulses in which the distance between two neighboring pulses is 30-40cm and the one between lines is 1-1.5m.

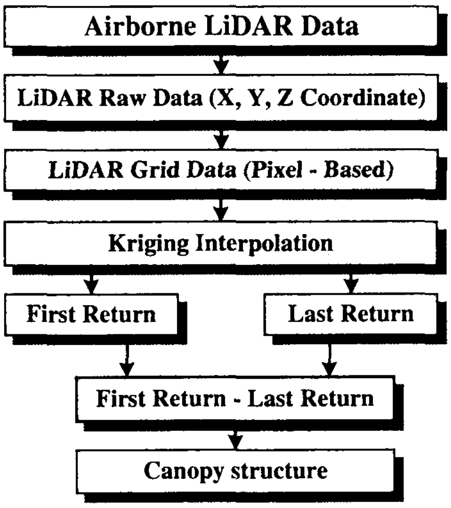

Fig. 3. Flow chart of processing the Lidar data.

Each Lidar raw data has the x-coordinate, y-coordinate, height, and intensity in ASCII form. In this preliminary study, the intensity data (which may have additional information related to the stand characteristics) were not analyzed. The average pulse density is about 1.5 point per $1m^2$. The raw data has been transformed to grid data (pixel-based) with $1x1m^2$ pixel resolution. As seen in Figure 2, the raw data have null value at regular spaced grid and need to be filled such empty grid cell by interpolation. Kriging interpolation algorithm has applied to fill the gap in grid space, which has been known as more reliable interpolation method than the traditional inverse distance weight method for the Lidar point data [11].

After the point data of the first and last return pulse were converted to 1m spaced grid data, the difference between the first return and the last return pulse was calculated for every cell. As seen in Figure 4, most of height differences (first return - last return) should be positive value. However, some of them show zero, which will be further discussed later. The coordinates of 14 sample stands were then overlaid to the layer of difference value and those pixels within each sample plot (a circle with 30m diameter) were extracted.

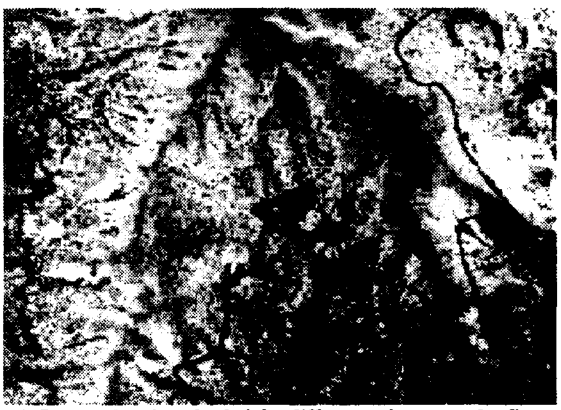

Fig. 4. Image showing the height difference between the first and the last return pulse.

3. Results and Discussions

Figure 5 shows images of the height difference between the first and the last returns of 14 sample stands. The gray scale in the image is proportional to the height difference, in which the completely black dots are zero value. The zero value indicates that the first return and the last return came from the same vertical height of canopy. In general, deciduous (H, Q) and mixed stands (M) are brighter than the other coniferous stands. The airborne laser data were acquired on April when the leaf growth is very early stage and total amount of foliage is minimal for most deciduous species. Therefore, the emitted laser pulse could have better penetration to the ground over the canopy of deciduous stands than the coniferous stands. Among the coniferous stands, larch plantation stands shows a little brighter tone. Larch is a deciduous needle leaf species and has about the same leaf growth pattern as other deciduous species.

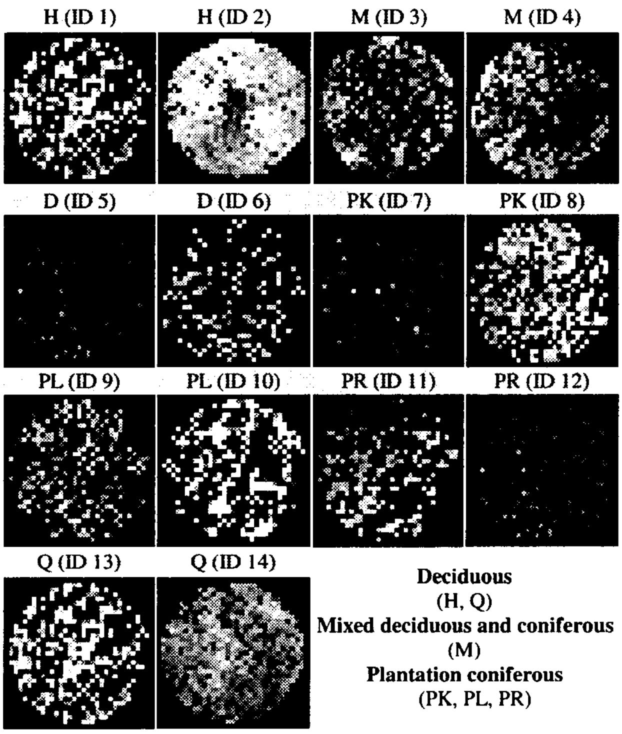

Fig. 5. Images of height difference between the first and last returns.

The interpretation results of the above images can be further verified by the statistics shown in table 2. The number of zero points in deciduous (H, Q) and mixed forest (M) is less than in coniferous forest. It has been known to many Lidar applications that the first pulse return has high probability of coming from the top of tree crown and the last pulse return comes from the ground. Therefore, the difference between the first and last returns is a indicator of tree height. However, very dense and fully closed canopy situation, the last laser pulse does not seem to come from the ground. The last pulse returns are mostly coming from the tree crown or branch, which makes low value in the difference image.

Table 2. Statistic report and percent of non-zero in result image.

ID	Stand type	$H_{first} - H_{last}$		No. of Zero Points	Percent of non zero
		Mean	Std		
1	H13C	6.101	1.462	56	92.28 %
2	H24C	10.732	1.774	18	97.34 %
3	M24C	7.693	2.869	255	65.82 %
4	M14C	7.583	3.216	255	65.82 %
5	D13C	4.916	2.226	479	36.03 %
6	D24C	7.867	4.548	544	27.39 %
7	PK12B	3.724	2.536	510	31.91 %
8	PK12C	10.111	2.894	288	61.43 %
9	PL12C	2.934	2.027	544	27.39 %
10	PL24C	12.494	7.961	318	57.44 %
11	PR12C	6.728	3.769	384	48.67 %
12	PR24C	7.63	3.582	419	44.02 %
13	Q14C	9.354	4.107	275	63.16 %
14	Q14C	8.474	1.571	10	98.40 %

Figure 6 shows the height profile of the first and the last return pulses along transect lines in deciduous stand (ID 1) and coniferous stand (ID 6). In the coniferous stands a large number of last pulses returned from the vertical position of the first pulse height. If we want assess the tree height we should use only those last pulses that hit the ground. In the deciduous canopy structure, last pulse height is mostly below in first pulse height, which may have better penetration due to the less dense leaf foliage of early leaf growing season.

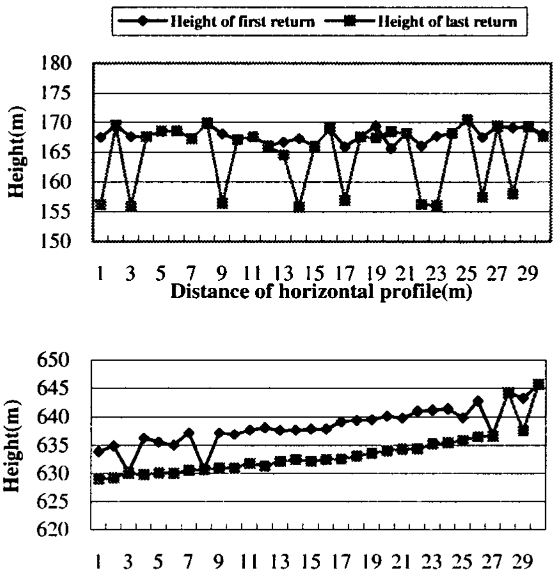

Fig. 6. Height profile of the first and the last return pulses along transect lines in deciduous stand (ID 1) and coniferous stand (ID 6).

4. Conclusions

Laser scanning technology has been increasing concern to assess and estimate the vertical structure of forest canopy, which is not usually achievable from traditional remote sensor data. In this study, we tried to evaluate the potential of airborne laser scanning data to describe forest stand characteristics over very dense canopy environment. From the preliminary analysis, we found that the difference between the first and last return was higher with deciduous forest stand than in coniferous stand. This is due to the less amount leaf foliage in deciduous forest when the data were acquired in very early season of leaf development of April. Although difference between the first and the last laser returns often corresponds to tree height, it would not be the case for the forest site having very dense canopy structure. Laser pulse may have difficulty to penetrate tree canopy at the forest of very dense canopy condition. Therefore, it needs to be cautious to use the simple difference between the first and the last laser return for the tree height estimation.

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