Generation of DEM Data Under Forest Canopy Using Airborne Lidar

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ABSTRACT:

Accurate DEM surface of forest floor is very important to extract any meaningful information regarding forest stand structure, such as tree heights, stand density, crown morphology, and biomass. In airborne lidar data processing, DEM data of forest floor is mostly generated by interpolating those elevation points obtained from last laser returns. In this study, we try to analyze the property of the last laser return under relatively dense forest canopy. Airborne laser data were obtained over the study area in relatively dense pine plantation forest. Two DEM data were generated by using all the points in the last laser returns and using only those points after removing non-ground points. From the preliminary analysis on these DEM data, we found that more than half of points among the last laser returns are actually hit from canopy, branches, and understory vegetation that should be removed before generating the surface DEM data.

KEY WORDS: LiDAR, DEM, forest floor, canopy, interpolation

1. INTRODUCTION

Primary applications of airborne laser scanner data have been accurate topographic mapping although there have been increasing numbers of other applications, such as forestry. 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. In such case, it is assumed that the last laser return represents the height of ground surface.

To generate digital elevation model (DEM) data under forest canopy, we often use only those last returns. However, it has been difficult to obtain the last laser return from the ground under very dense canopy situation. The laser penetration rates of laser pulse were lower than 30% when the canopy closure is over 80% (Cowen, 2000; Flood, 1997; Kraus, 1998). Therefore, it may not be valid to assume that the last laser return comes from ground surface. To generate more accurate DEM data of ground surface in forest, we should pay more attention on where the last return comes from. If there is considerable amount of points hit from other than surface, we should remove those points among the last returns before generating DEM data.

In urban area, there have been a few methods to separate only those points representing ground surface (Vosselman, 2000; Lee, 2005). It is relatively rare to find the characteristics and processing method of the last laser returns in forested area. The objectives of this study are to analyze the property of the last laser return under relatively dense forest canopy and to find suitable method to remove those points that are not from ground surface.

Accurate DEM in forest can be essential to extract tree heights from airborne lidar data.

2. METHODS

2.1 Study Sites and LiDAR Data Acquisition

The study area located in Mt. Umyung in Kyungkido and the forest type in this area is mainly plantation stands of pine (*Pinus koraiensis)* and larch *(Larix leptolepis)*. We have selected the study sites, in which the site includes somewhat steep slopes (Figure 1).

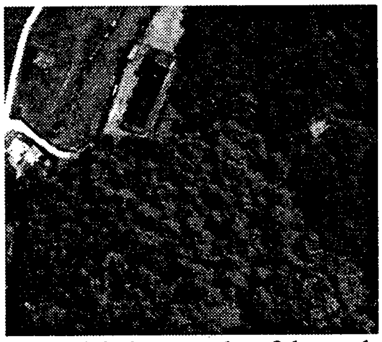

Figure 1. Aerial photographs of the study site.

Airborne lidar data was acquired using Optech ALTM 30/70 system on April 28, 2004 (Table 1). The plane was flown at altitude of approximately 1,500m with total 5 flight lines. The scan angle was ±20 degrees 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 30/70 is a discrete pulse laser system that can record the returned signal four-times for each transmitted pulse.

Table 1. Lidar specification of Optech ALTM 3070.

Flying height	Horizontal accuracy	Elevatio n accuracy	Laser footprint	Pulse densit y	Repetitio n rate
1,500m	≒0.75m	< 20cm	30 cm	0.86 point/m^2	70kHz

During the lidar data acquisition, digital color aerial photographs were also acquired. 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 aerial photographs were used to extract the elevation of ground surface.

2.2 Analysis of the last laser returns

To generate the DEM data for the ground surface under the forest canopy, the first three laser returns were removed from the initially processed lidar elevation data. Initially, all points of the last laser return were used to generate the ground surface DEM without any modifications. However, as seen in Figure 2, a lot of laser points are distributed with the same height as the first returns. Since the study sites have relatively dense forest canopy, even the laser pulse cannot completely penetrate the canopy layer. Eventually, many last points are hits from canopy, branches, and understory vegetation, such as brush and shrub.

Figure 2. Vertical profile of the lidar pulse hit of the last returns (black) as compared to the first return (grey tone).

Considering that great portion of the last laser returns do not correspond to the ground elevation, we try to exclude those points bounced from other that the ground. To select only those points hit from the ground, we applied a method developed mainly for the processing of lidar points in urban area (Terrasolid Inc.). This method requires several input parameters of the size of a pseudo grid, the nearest distance between points, and the maximum allowable vertical angle between points. The appropriate values for these parameters are determined empirically using the terrain data and field survey data over the study area.

2.3 DEM Generation and Accuracy Assessment

Two types of DEM data were generated by different set of elevation points of 1) all the points in the last returns and 2) only those points after removing non-ground points from the last returns. There are several interpolation algorithms and each one has advantages and disadvantages over another from the aspects of processing time, accuracy and terrain characteristics. In our study, we initially used nearest neighbour method that showed very similar results with triangulated irregular network (TIN) methods.

Size of DEM grid is another important factor to determine the quality of DEM data. Morgan(2002) suggested that DEM grid size should be approximately $1/\sqrt{n}$ m when point density is n/m². Since two datasets of elevation point have different point density and they have rather irregular distribution, it was difficult to determine the appropriate grid size. We determined 0.5m grid size to keep the maximum variation of height difference.

To assess the accuracy of two DEM data generated, probably differential global positioning system (DGPS) surveying would be the optimum method. However, the receiving the GPS signals under the forest canopy was rather difficult. Instead, we extracted the reference elevation values from the stereo pair of digital aerial photographs that had been corrected and triangulated. The elevation values obtained from the digital photogrammetry were compared and confirmed by the DGPS surveying conducted over the test points in nearby open area.

3. RESULTS AND DISCUSSIONS

As seen in Figure 3, the 3-D views of two DEM data generated over the study area show very distinct pattern in the height variation of the ground surface.

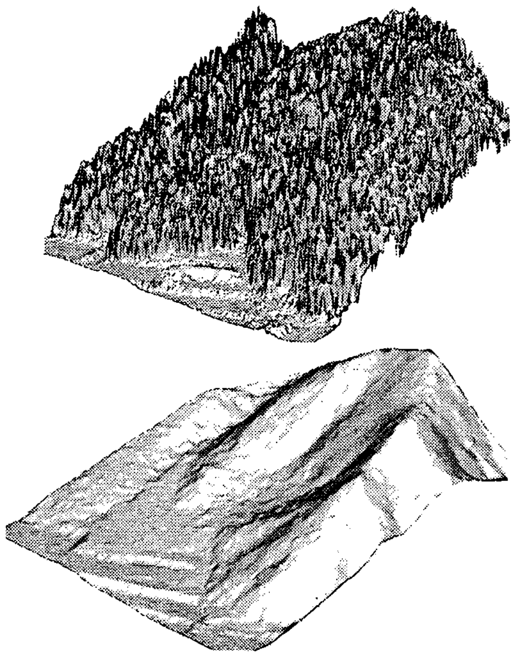

Figure 3. 3-D view of DEM data using the entire last laser returns (top) and using only ground points (bottom).

The DEM data generated by using the entire points of last laser returns looks very rough surfaces, in which the irregular vertical features seem to be trees. These points are probably corresponding with the laser returns from other than forest floor. The DEM data obtained from only those points corresponding to the forest floor do not show such vertical features and look relatively smooth surface.

Table 2 compares simple statistics of two DEM data over the study area. The mean elevations difference between two DEM data is 8.72m, in which the DEM data using the entire last return points show higher elevation. As might be seen in Figure 3, it is natural to see the higher elevation from the DEM data using the entire points of last laser return, since great portion of those points are representing other than forest floor. From the field survey on the forest stands, we found that the average tree height of the plantation pine stands were about 24m. Therefore, the discrepancy between two DEM may be caused by the laser points hit from tree crown, branches, and understory shrub.

Table 2. Comparison of statistics between two DEM data.

	DEM using entire last returns	DEM using only ground-hit points	Residual
Mean(m)	311.94	302.92	8.72
Std(m)	25.42	22.35	7.26
Max(m)	375.67	357.44	46.41
Min(m)	271.14	271.07	-0.01

Figure 4 shows the histogram of elevation of last return points corrected over a $20x20m^2$ area. The histogram clearly shows the two groups of points representing the forest floor and non-ground hit.

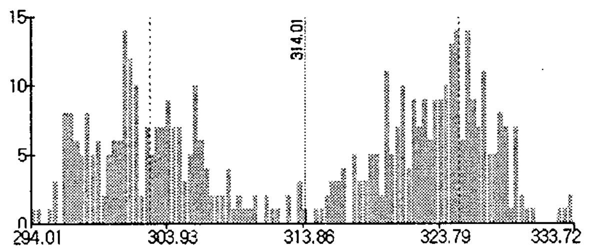

Figure 4. Distribution of elevation points of last laser returns within a $20x20m^2$.

The accuracy of the DEM data using only those points of ground hit was evaluated by the reference points obtained from digital photogrammetry (Table 3). Mean residual between the reference points and the DEM is 30.7 cm, which seems to be reasonable to be used for any forestry applications as well as precise topographic mapping in forested topography.

4. CONCLUSIONS

We should pay more attention on the generation of DEM by airborne Lidar data, in particular for the area under relatively dense forest canopy situation. Although DEM data of forest floor have been frequently generated by interpolating points of last laser returns, it may not be appropriate solution in forest. In this study, we found that about half of the points within the last laser returns do not correspond with the forest floor. They are laser return from tree crown, branches, and understory vegetation and should be removed from the last returns before generating the DEM of forest floor. Further study is necessary to have more effective and accurate methods to select only those points corresponding the forest floor.

Table 3. DEM accuracy assessed by reference points.

Point	Reference elevation	Ground points DEM	Residuals
1	275.807	275.963	- 0.156
2	300.831	300.454	0.377
3	280.102	279.722	0.380
4	275.930	275.660	0.270
5	346.772	346.106	0.666
Mean residuals		0.307	

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