

DERIVATION OF DIGITAL TERRAIN MODEL IN FORESTED AREA WITH AIRBORNE LIDAR DATA

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ABSTRACT:

Detailed high-resolution digital terrain model can be obtained in open area using airborne laser scanning technique. But in forested area, how to extract high accuracy digital terrain model still needs to be researched. In this article, a filtering strategy based on multiple pulses and height variation analysis is introduced. According to the 3D visualization observation of the data collected by airborne laser scanner, quite a number of terrain points exist in single pulse and last pulse, so, on the basis of the characteristics of single pulse and multiple pulses and the height variation between points, the final terrain points are filtered from the two datasets in our study. At last, the digital terrain model is obtained by the interpolation using the filtered terrain points. The experiment result shows that the filtering method performed well in forestry.

1. INTRODUCTION

In the past few years, airborne laser scanning (ALS) has become a highly automated method for acquisition of accurate DTM (digital terrain model); it performs much better than traditional photogrammetric stereo measurements especially in forested areas. In forestry, only a small number of rays can reach the terrain in photogrammetric measurements, the ground is covered by dark shadows, but with laser scanner technology which is independent of the sun, the shadows do not pose any problem (K. Kraus & N. Pfeifer, 1998).

To generate a DTM using LiDAR data, 3D terrain points have to be separated from vegetation points, namely filtering. Various filtering algorithms have been proposed. Kilian et al. (1996) presented the first ideas to generate DTM from LiDAR data in wooded area on the basis of morphological opening operation. Kraus and Pfeifer (1998) introduced the linear prediction into the DTM generation. Axelsson (1999) described a method based on progressive densification of a triangular irregular network (TIN), a surface is allowed to fluctuate within certain values and points from the point cloud are added to the TIN during iteration, these iterations proceed until no further low ground points can be added any more. Vosselman (2000) proposed a slope based filtering method which uses height difference between points as the criteria to judge the point is a terrain point or not. A hierarchical grid-based approach was proposed by Wack and Wimmer (2002), the Laplacian of Gaussian operator in combination with a weight function is utilized to detect and remove the points that are not considered to be terrain points. Zhang et al. (2003) utilized the classical morphological opening with gradually increase the size of the structuring element to remove the vegetation points. H. Arefi & M. Hahn (2005) proposed a morphological greyscale reconstruction algorithm to separate vegetation points from terrain points, it uses the geodesic dilation which employs the

elementary isotropic structuring element that does not need to select structuring element sizes. Kobler et al. (2007) introduced a REIN filtering algorithm.

Unlike the point based filtering method described above, some algorithms based on groups of points, called segmentation based algorithms were proposed, points are grouped into segments according to homogeneity criterion (Sithole, 2005; Nardinocchi et al., 2003), subsequently, D. Tóvári and N. Pfeifer (2005) introduced a new filtering method combining both the point based method and segmentation based method.

The forest cover caused a loss in terrain details and introduced interpolation errors in DTM (Xiaowei Yu, et al. 2005). In forested area covered by dense vegetation, less laser beam can penetrate the vegetation to reach the ground than in open area, which is adverse for acquiring enough terrain points to obtain the highly accurate DTM, the terrain slope also affects the filtering results. Raber et al. (2002a) and Hodgson et al. (2003) found that land-cover type were a significant factor that influences the accuracy of DTM in forested areas. The more open the area, the more accurate the laser-derived DTM, and the data obtained in leaf-off conditions were found more suitable for mapping the terrain surface than data obtained in leaf-on conditions (Raber et al. 2002b). The factors influence the quality of DTM derived from laser scanning can be grouped as three kinds, errors caused by equipment for data acquisition, errors caused during data processing and errors caused by the characteristic of measured target. The last factor is the one can not be changed subjectively, therefore, in order to improve the accuracy of DTM we can only count on improving our equipment and way of data processing.

In this article, we propose a point based filtering method on the basis of the multiple pulses and height variation analysis between nearby points. In section 2, the filtering strategy will be explained in detail. In section 3, the method is used in the

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real laser scanning data processing, and the result is analyzed. Finally, the discussion based on the experiment result will be presented.

2. STUDY AREA AND METHODS

2.0 Study area

The study area is located in western Washington near Olympia; it is a part of Capitol State Forest and is managed by the Washington State Department of Natural Resources. Forest canopy within the study area is primarily coniferous and highly variable, and forest plantations ranging in age from recently planted to 70-year-old mature forests. The canopy of the 70-year-old forest stand was partially harvested in 1998, resulting in four different residual canopy density classes.

A small footprint, discrete return LIDAR system was used to map the study area in the spring of 1999. A Saab TopEye LIDAR system mounted on a helicopter was used to collect data over the study area. Table 1 presents the flight parameters and instruments settings for the data acquisition. Each return includes the pulse number, return number for the pulse (up to four returns were recorded per pulse), X, Y, elevation, off-nadir angle and return intensity. We chose 100,000 points from the whole dataset. The height in the chosen data varies from 230 to 350m, the area is about 0.75km².

Flying height	200 m
Flying speed	25 m/sec
Scanning swath width	70 m
Forward tilt	8 degrees
Laser pulse density	4 pulse/ m ²
Laser pulse rate	7,000 points/sec
Maximum returns per pulse	4
Footprint diameter	40 cm

Table 1. Flight parameter and scanning system settings

2.1 Single pulse and multiple pulses analysis

Laser beams have the capability of penetrating the vegetation and the receiver can record the corresponding energy signals reflected from object during its transmission path. Multiple pulses are regarded as an important characteristic in distinguishing the terrain points and vegetation points. Generally speaking, multiple pulses happen when the laser beam penetrate the vegetation, in which the first pulse echoes represent almost the highest part of vegetation, the last pulse echoes are considered as the terrain points. The DTM is usually simply obtained by the single pulse and last pulse in former research. In open area, this will not cause too much problems, but in the forested area with dense vegetations, it is difficult for the laser beam to penetrate the vegetation to reach the ground, many last pulse echoes actually are reflected by the bunches or leaves of the lower part of the trees, and the single pulses are reflected by the crown of the trees (figure 1, 2), hence the construction of DTM can not only depend on the whole last pulse echo. In order to get high quality DTM, we have to extract terrain points from single pulse and last pulse echo respectively. The flow chart of data processing is shown in figure 3.

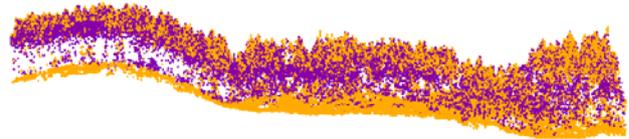


Figure 1. The single pulses (golden points) are overlapped with the first pulse echoes (purple points); it shows that quite a few single pulses are reflected by the crown of trees

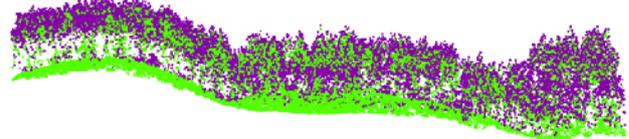


Figure 2. The last pulse echoes (green points) are overlapped with the first pulse echo (purple points); we find that some last pulse echoes are reflected by bunches or leaves of trees.

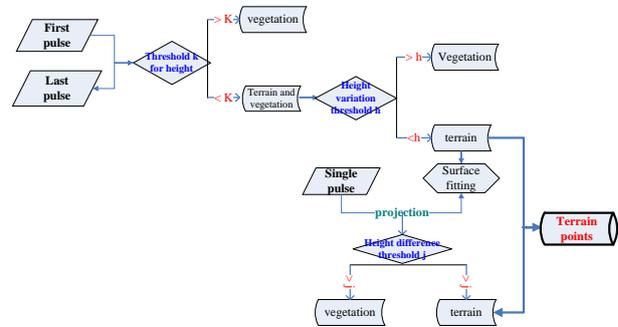


Figure 3. The work flow chart of filtering method.

2.2 Extract terrain points from last pulse echo

Theoretically, the last pulse echoes are reflected by ground or the lower part of the trees, and the first pulse echoes are reflected by the highest part of the trees, obvious height difference will exist between first pulse echo and its corresponding last pulse echo. Hence, in the first phase of filtering, we set an initial threshold, 20 meters, to roughly eliminate the vegetation points from last pulse echoes. It means that the points in last pulse echoes with height difference larger than 20 meters are considered to be the terrain points temporarily. Obviously, due to the influence of terrain slope, some vegetation close to the ground can not be eliminated successfully by the threshold simply set. In the second phase, height variation between point waiting for processing and its nearest point was analyzed. The height variation was calculated using the equation below (equation1):

$$HV_{i,i-1} = \frac{|Z_i - Z_{i-1}|}{Dis((X_i, Y_i), (X_{i-1}, Y_{i-1}))} \quad (1)$$

where $HV_{i,i-1}$ = height variation between the two points
 Z_i, Z_{i-1} = height value between the two point
 $Dis((X_i, Y_i), (X_{i-1}, Y_{i-1}))$ = planar distance between the two points

According to the equation above, we calculate the height variation for each pair of points and the statistical table (table 2) and graph (figure 4) have been done.

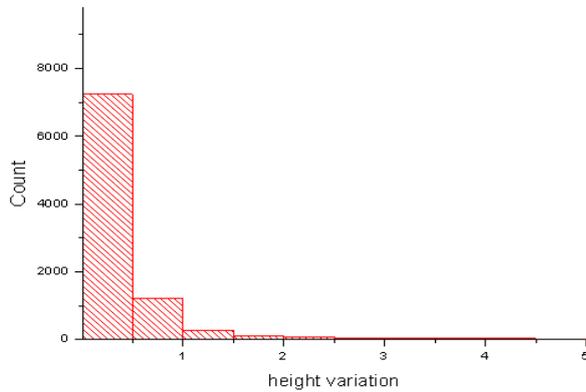


Figure 4. Statistical graph for height variation, the horizontal axis is the height variation with spacing 0.5, and the vertical axis is the count for each bin.

Bin	Count	Percentage
0.25	7247	78.05
0.50	1219	91.18
0.75	273	94.12
1.00	105	95.25
...

Table 2. The statistical table for height variation, the first column represents the spacing of height variation in statistic, the second column represents the count of the points whose height variation included in the bin, and the third column represents the percentage of the points compared with the whole dataset.

The height variation, in other words, the change in vertical direction correlative with the planar distance between the two points, is taken as one criterion in filtering. The terrain points will have tempered change while it is relatively abrupt for off-terrain points. Based on the statistical result of height variation, we found that 91.18% of the points have height variation less than 0.5, meanwhile, the count of points whose height variation above 0.5 is decreasing suddenly. In order to eliminate the few off-terrain points, the points with height variation above 0.5 are excluded. After the two steps filtering described above, 14177 points, about 58.6% of the terrain points are extracted from the last pulse echo.

2.3 Extract terrain points from single pulse

The filtering result in last pulse echoes is the basis for the extraction of terrain points from single pulses in our method. Terrain points filtered out from last pulse echoes were fitted to a smooth surface, and then all the points in single pulses were projected onto the surface to calculate corresponding height values, the height values were compared with the original height values before projection. The statistical graph (figure 5) and table (table 3) of difference between recomputed height and original height are shown below.

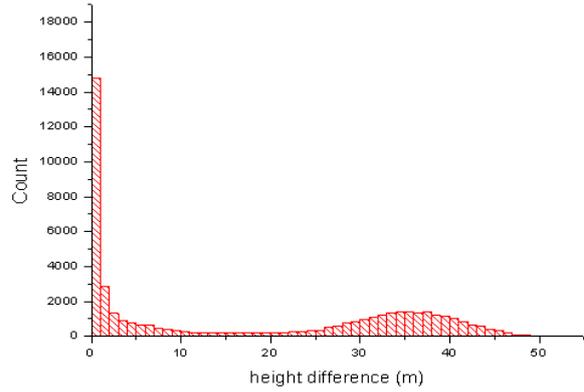


Figure 5. Statistical graph for height difference, the horizontal axis is the height difference with spacing 2 meters, and the vertical axis is the count for each bin.

Bin	Count	Percentage
-1	0	0
1	17576	38.11
3	2233	42.95
5	1439	46.07
...

Table 3. The statistical table for height difference, the first column represents the spacing of height variation in statistic, the second column represents the count of the points whose height difference included in the bin, and the third column represents the percentage of the points compared with the whole dataset.

The single pulse is either reflected by the crown of trees or ground, so its height difference varies from zero to 53m, the point has smaller height difference is much closer to terrain. The points with height difference below 1 meter were accepted as terrain points in single pulse. Finally, the terrain points extracted from last pulse echo and single pulse, 24854 points, about 25% of the raw points, were combined together to construct DTM for the forested area.

3. RESULT AND CONCLUSION

3.0 Experiment results

Table 4 shows the filtering result from the single pulses and last pulse echoes respectively, in single pulses, 23% points were belong to terrain in single pulse and 57.3% points were belong to terrain in last pulse echoes.

	Total	Terrain	Vegetation
Single pulse	46120	10677	35443
Last pulse echo	24735	14177	10558

Table 4. The terrain points and off-terrain points included in single pulses and last pulse echoes after filtering

The final terrain points extracted from single pulses and last pulse echoes are interpolated into a grid to construct the DTM (figure 6), and the raw data before filtering were also interpolated into grid for comparison (figure 7).

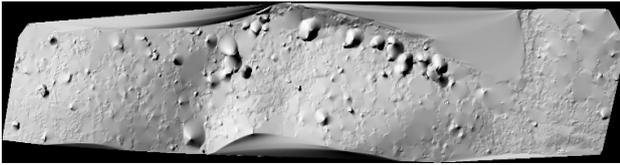


Figure 6. DTM after filtering, there are still small quantity of off-terrain points are not eliminated resulting in the protuberance above the terrain.

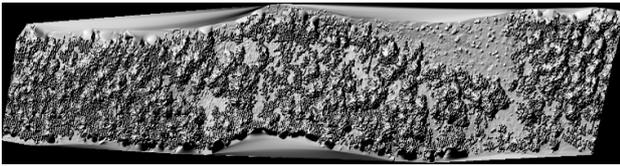


Figure 7. Relief of raw data before filtering.

Because we don't have reference data to complete the quantitative analysis of accuracy, the terrain points filtered were overlapped with the off-terrain points to check visually (figure 8).

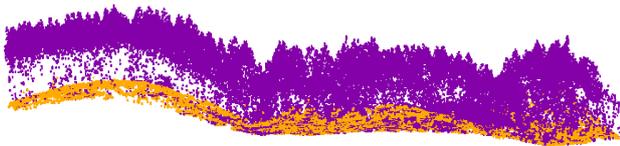


Figure 8. Terrain points overlapped with off-terrain points, the golden ones are terrain points, and the purple ones are the off-terrain points. It is shown that the terrain points are basically separated from the off-terrain points.

3.1 Conclusion

In this article, we presented the filtering method based on the multiple pulses and height variation analysis, by applying this method in the forested area covered by dense vegetation. The experiment result shows that this method performed well in separating the off-terrain points from terrain points. Utilizing the distinct difference between last pulse echoes and first pulse echoes in vertical direction, we obtained elementary filtering result. Then, the height variation helped us to eliminate vegetation points left. Based on the surface calculated by the result described above, the terrain points in single pulses were extracted. The two parts terrain points form the basis of DTM construction.

In the final result, small quantity of vegetation close to terrain was not eliminated resulting in the protuberance on the terrain. The threshold we chose in filtering influences much in the filtering, if the threshold is too large, terrain points will be lost, but if the threshold is too small, vegetation points can not be eliminated successfully. And in our method, the result in each phase has strong correlations to each other, for instance, the filtering in last pulse echoes will affect the filtering in single pulse directly.

The experiment demonstrates this method has good performance in forested area; visually the procedure is already

working quite well. Future work will focus on how to choose much more suitable threshold and the quantitative accuracy evaluation of the filtering result.

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