

High Fidelity DEM Generation Based on LiDAR Data

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Abstract—With favorable penetrability to vegetation, LiDAR data is an important data source to generate high precision DEM for reconnaissance and design of railway. To avoid the limitation of the LiDAR data-processing in keeping terrain feature and to satisfy the demand of the reconnaissance and design, this paper presents a high fidelity DEM production method, which successively uses the specialized software and the variety photogrammetry technology. The large scale results of production have proved that the method is feasible and useable.

Index Terms—railway survey, airborne LiDAR, filter, digital elevation mode

I. INTRODUCTION

LiDAR (Light Detection and Ranging) technology provides an effective and reliable measurement to get topography over large areas. Now, it becomes a main method to generate high precision DEM that are essential to numerous applications in industry application prospect [1, 2, 3]. LiDAR systems usually get dense footprints with three-dimensional coordinate information. The information which called footprints are not all on the real terrain surface, some on artificial buildings (roofs, chimneys, towers, etc.) and some on vegetation (trees, bushes, grass, etc.). In order to generate DEM (Digital Elevation Model), we must eliminate off-terrain points and this is filtering of LiDAR data.

There are many filter methods have been used to get ground points from LiDAR data by using different principles [4,5,6], but they either is not feasible in complex terrain[4], or is difficult to get the thresholds to discriminate non-ground points and ground points [5], or has too many parameters to preset, which seriously slows down the processing speed [6]. There is some other filtering arithmetic which is use mult-kinds data, such as intensive data, digital photo data, GIS data, etc. Some scholar fuse high-resolution image data and LiDAR data to get higher classification accuracy [7, 8], but they have not been used in actual application for their a little universality.

Nowadays, In China very arduous railway construction has brought huge pressure for the Railway Survey and

Design, which has the tight schedule and high precision characteristics. And the aerial photogrammetry, getting ground information fast and highly effective, is very helpful [9]. The production process and operation mode of the aerial photogrammetry technology is fixed and mature. However, there are some factors affecting the aerial photogrammetry, such as weather, airspace coordination, tree mask [10], high accuracy, etc. While the LiDAR technology can be used in railway reconnaissance because it can get high precision and fidelity DEM fast and convenient, and can adapt to the weather. LiDAR technique applied in railway survey can reduce human resource investment, improve the quality and efficiency of the survey and promote railway survey and design, and even the construction and operation. The economic benefit and social benefit are very prominent, and the DEM products generated by LIDAR are used widely. But the flow of the LiDAR generating DEM is far from maturity, so we should grope and summarize ourselves [11].

In this paper, we combining the TerraSolid software, aerial photogrammetry and some other methods purpose a new method of production of DEM by LiDAR. We utilize this method in practice and get mass data which prove our method is feasible.

II. THE RAILWAY SURVEY CHARACTERISTIC AND ITS DEMAND TO DEM

In large and middle railway construction engineering, there are two stages: Project Decision-making Stage which contains pre-feasibility study and feasibility study, and Project Implementation Stage including Preliminary Design and Construction Drawing Design. Pre-feasibility study mainly carries on the plan of the project. In this stage engineering quantity requirement is low, so collecting small scale Topographic Map and low accuracy DEM is enough. The feasibility study stage determines the construction period and the investment estimation according the project proposal, which need to do middle scale Surveying and Mapping. The Preliminary Design stage determine the construction scale and the main basis for investment which is according to the approved feasibility study report

including the plane and elevation control survey, center line survey, cross section survey and some related professional survey. This needs accuracy and fidelity DEM data.

There are two major applications of DEM in Railway Survey and Design:

- Visual analysis based on DEM, including large area railway route selection and scheme selection;
- Key worksite and engineering terrain data calculation, including horizontal-longitudinal section extraction, contour drawing, Topographic map making and so on.

The accuracy of DEM data applied in railway survey should be applicable to different design. The large area railway route selection and scheme comparison can use regular grid which interval 5-10 meters. Firstly translate the DEM data into floating-point and save as the Tiff format file. Then we can show different effects, route scheme display, surrounding topography display, terrain filling-digging effect display, by Tiff file. To key worksite should use the "TIN constructing-net + characteristic line" format and the interval is 1 meter.

Overall, the DEM used in railway survey is mainly strip map. Nearby the railway need high accuracy plane and elevation data, while far from the railway the accuracy can be properly reducing. And the large area railway route selection can use smaller scale DEM data.

III. METHODS OF THE LiDAR DATA GENERATION

A. Adaptive TIN Method

The adaptive TIN method is proposed by Axelsson [12] in 2000. Firstly, getting certain seed points compose the initial TIN (Triangulated Irregular Network), then judge each point, if the vertical distance and angle between this point and the triangular facets small than the given threshold, join this point to the ground points set. Secondly, recalculate the TIN composed by all ground points set, and then judge the points not in the ground set. So do this iteration until no longer increase the new ground point or meet given conditions. The key point of this method is the threshold selection. Different threshold will produce different result.

Commercial LiDAR data processing software has improved this method. In practice, need to set many parameters like removing singularity, setting search radius, limiting search range. When separate ground points, need to set iteration distance (d) and iteration angle (α , β , γ). Iteration distance is the vertical distance between current point and projection point of the triangular facets. And the iteration angle is the angle which is showing in Fig. 1. We have to find the best iteration angel and iteration distance according to different vegetation cover and topographic relief [13].

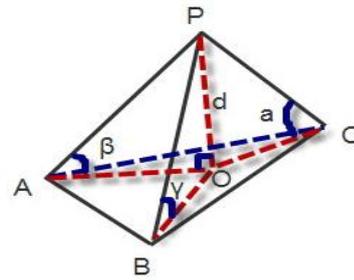


Figure 1. The parameters setting of the TerraSolid filter.

B. Window Changing Method

This method is proposed by Kilian [14] et. in 1996. The method can get the DEM of the interpolation forest areas. Firstly, get a window and find the lowest point of this window, then set the points whose distance to lowest point smaller than the given threshold as the ground points. According to the size of the window, give the data certain weight, and move the window on the whole image will get the DEM. Secondly, do this several times with different size of window, and different window sets different height. At last, all results carry on the weighted average, and set the points which over the threshold as the ground points, and the get the final DEM. Experiment has proved that this method is much quick, and its effect is also satisfying.

C. Iteration Least-Square Interpolation Method

The iteration least-square linear prediction method is firstly proposed by Kraus and Dfeifer [4], from the University of Vienna, in Austria, and it is used to remove the tree points of the forest area. And the commercial software Scop++ takes this method.

This method uses polynomial curve to analysis the elevation of the laser footprint. The elevation of the object points is higher than the surrounding terrain points, and there can be interpolated a fitting surface. Now, the difference between the elevation of the laser footprint and the fitting surface is not obeying the normal distribution. The deviation of object points is positive, and the deviation is relative bigger. While the deviation of ground points is negative, and the deviation is relative smaller. So we can distinguish the ground points and other points. Firstly, get the initial fitting surface model by computing the laser footprint elevation's average. This surface is between DEM and DSM. Then compute the deviation of the laser footprint elevation and fitting surface, and use this deviation to get the weight of each point. Set the point, whose deviation is much bigger, with bigger weight, and set the point, whose deviation is in the middle range, with the relative small weight. And set the point, whose deviation is bigger than the threshold, with 0. Last, refit the surface model with the new weight. So iterate it like this until meeting termination condition.

D. Characteristic of Common Commercial Filter Software

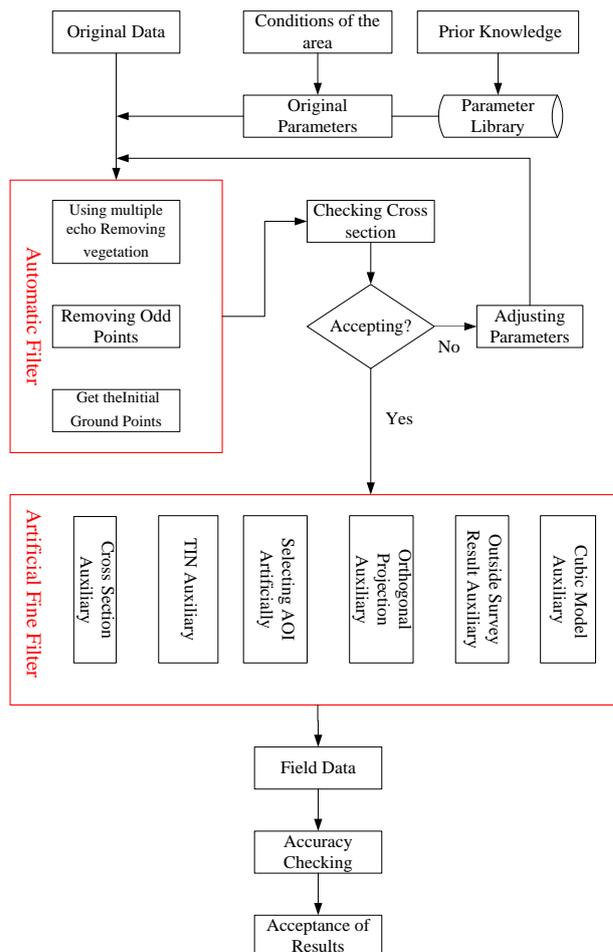
At present, in the actual project, the commercial software uses the software which is stable and convenient. But in practice, there also have certain defects. Take TerraSolid as an example. Firstly, separate the vegetation and eaves from ground points utilizing multiple echo information, then separate the singularity using partial statistics. And then using TIN iteration separate the ground points. In this process, each step needs to choose different parameters according to different terrain. As the mainstream LiDAR data processing commercial software, TerraSolid has some advantages: relative stabilization result, higher automaticity, interactive functions and so on. However, this method has obvious shortcoming. We have to set a lot of parameters. So, just automatic classification can't satisfy the demand of the project. We need artificial participation to modify the automatic classification result.

IV. METHOD AND PROCESS OF LiDAR POINTS CLOUD FILTER IN RAILWAY SURVEY

Points cloud can be divided into two parts according to the application: area points cloud filter and belt points cloud filter. Area points cloud filter is mainly about the contour, while the belt points cloud filter is mainly about vertical and cross section. Difference of the two filters method is involving different key. One is about “line”, and the other is about “facet”. So in the process of filter the focus is different. In this paper, according to the characteristic and the production experience, we propose a new method of DEM generating process which can consider both the railway survey efficiency and the accuracy of the DEM data.

A. The Main Flow

Firstly, we set the parameter library according to the prior knowledge. To different terrain, vegetation intensive, building number, data collection season, laser footprint number, we divide into different class. And each class corresponds to different parameter library which is verified effect. Then in the process realize fast automatic filtering. According to different stage of the railway survey, use different method to process the filter results. At the route selection stage, use 3D-view to observe the filter result, and modify the relative big deviation. At the Construction Drawing Design stage, use TerraSolid software to process the filter result, remove the scattered point. And then can modify the result by orthogonal projection auxiliary filter. To nearby railway data, because of the high accuracy demand, use the outside survey result auxiliary filter and cubic model auxiliary filter. These methods have the characteristic: high accuracy, result stable and reliable et. However, they also have disadvantages which need specialized operators, and instrument equipment. The flow diagram is showed in Fig. 2



And the key point is:

1) Partition processing

Usually the Railway Survey and Design has to survey large area, and has large data quantity. Some files even larger than 1GB. It is necessary to separate the huge file into several files. Firstly it can reduce the complexity of the terrain, and we can use uniform parameters in Automatic filter. Secondly, it can reduce the complexity of the data processing, and we can use lower-end computers and get faster speed. When partition, should accord to the software and hardware conditions and the terrain and vegetation conditions. When the partition is too large and the terrain and vegetation is uneven distributed, this will cause massive wrong distinguish (the yellow points stand for ground points, and the white is the others). If divide this area into 4 parts, and do filter process for each part. The result is greatly improved. See Fig 3. Usually, we should keep the numbers of the LiDAR footprints lower than 8 millions.

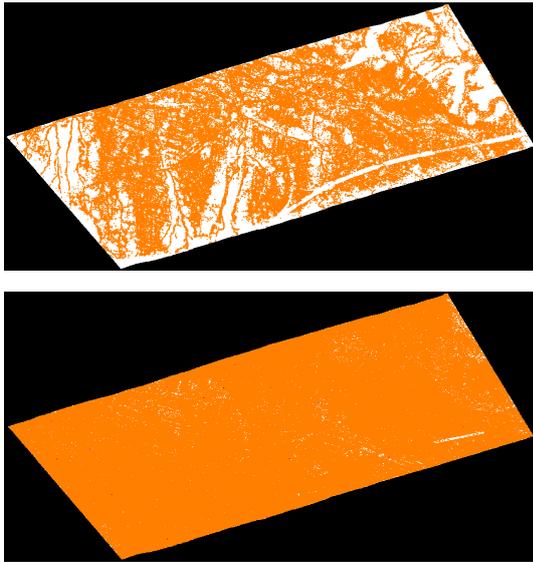


Figure 3. Partition process effect comparison. The left has no partition, and the right has partition.

2) Removing vegetation

When LiDAR beams illuminate some objects, such as vegetation, edge of buildings, it can get several returns. So, using multiple echo information, remove the first echo and middle echo points which are mainly vegetation. This can reduce a lot of process work.

3) Parameter setting

According to the prior knowledge, we can get the general rules of the character of natural landscape. We can build parameter library. When process the LiDAR data, we can determine the initial parameters such as the iteration distance and iteration angles, by the topographic grade (plains, hills, mountains, rural area, urban area, etc.) and state of the data acquisition (season, solar altitude angle, etc.), from the parameter library.

4) Automatic filter

Use TerraSolid to realize automatic filter, including single low point and group low points, singular high point. According to different terrain, set parameters and use macro command to process the LiDAR data, and then get the initial ground points.

5) Manual fine classification

The data after macro command processing have commission error and omission error in partial, especially nearby the railway. So there need to carry on finer filter artificially.

B. Method of Artificial Fine Filter for LiDAR

1) Cross section auxiliary filter

This method is most commonly used. Use truncation surface software to truncate along the line, and show it in a single window. Through observation of the points projected on the cross section judge the correctness of automatic classification. If the classification is not correct, use the point cloud classification tools to edit artificially, and reclassify. See Fig 4.

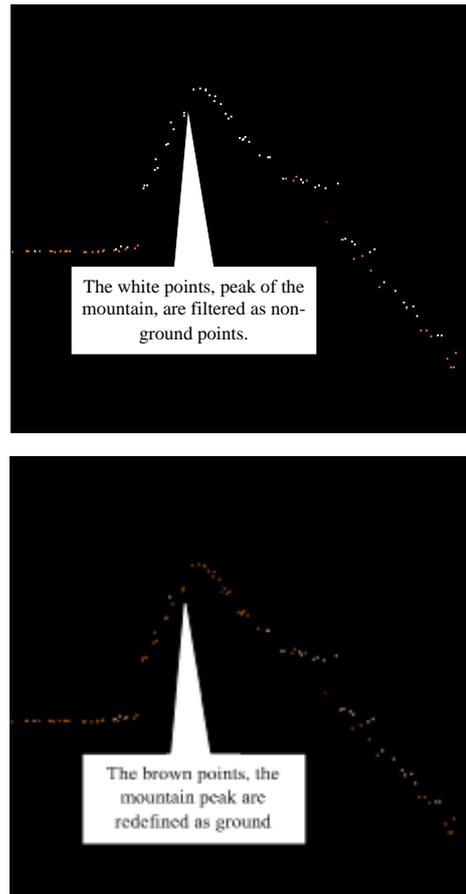


Figure 4. Filter supported by Cross-section (Left: before correction; Right: after correction).

2) TIN auxiliary filter

Using divided ground points to renew the TIN model real-time. And utilize surface roughness of the TIN model to judge the filter result. In general, we assume the surface of the earth is piecewise smooth, which is the surface is smooth in most area. So, if we observed that someplace is very roughness from the TIN model, we can get the conclusion, there must have some wrong. See Fig 5.

3) Selecting AOI artificially filter

Because of the difference of the terrain, it is hard to get good result with automatic filter. Take mountain area as an example, different mountain has different slope, and different direction of a mountain also has different slope. In that case, one set of parameters can't judge correctly. So we use the AOI auxiliary to modify the parameters and improve the effect of filter. See Fig 6.

4) Orthogonal projection auxiliary filter

Classify the DOM, which is matched with laser cloud points, artificially. And add this classification result to the orthogonal projection, then judge the filter effect conveniently, which is showed in Fig.7. The laser footprint on the roof is wrongly classified into ground points (magenta), which is needed to modify artificially.

5) Outside survey result auxiliary filter

In the dense vegetation region, ground laser points are relatively small and not enough to build real terrain

model. So we can use the outside survey result to assist classification, which is showed in Fig.8 below. The white box represents the actual ground point. With these points, we can roughly determine the trend of the terrain (green line), and thus correctly classify the nearby points.

6) Cubic model auxiliary filter

In some cases, we can't determine the correctness of filtering results of the point cloud only by the cross-section and TIN models. Based on the cubic model, with the true three-dimensional visual observations, we can greatly determine the classification of laser footprint, which greatly improve the accuracy of the point cloud filtering. There are two main sources of the cubic models. One comes from the aviation stereo images of measurement camera and the other is from 3D model, obtained from digital photos of the non-measurement camera in airborne LiDAR system.

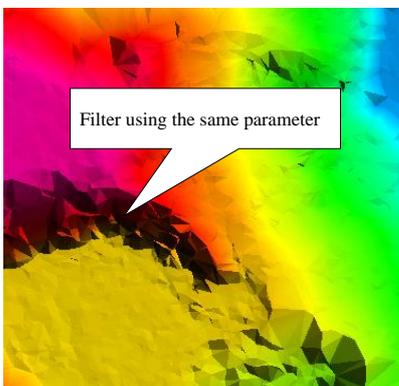
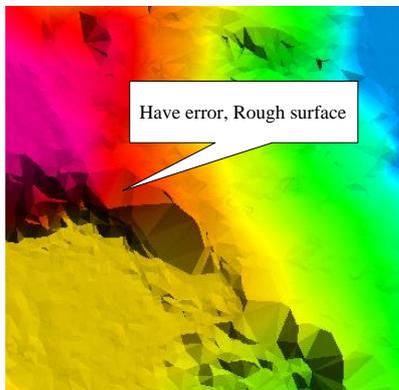


Figure 5. Filter supported by TIN model.



Figure 6. Filtering using outside survey points.

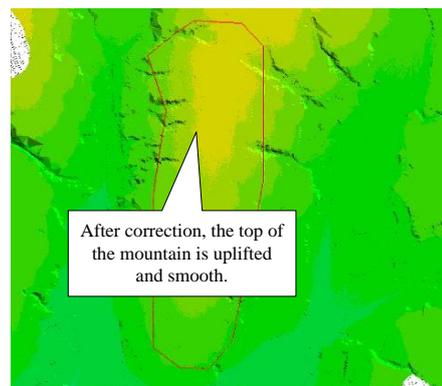
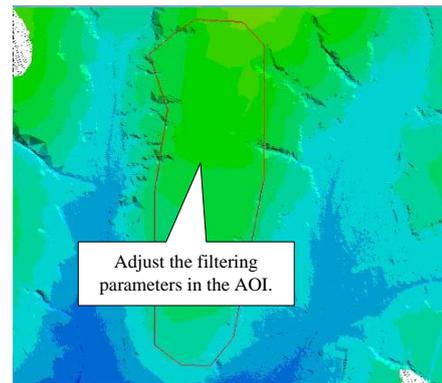


Figure 7. Manually drawn AOI.

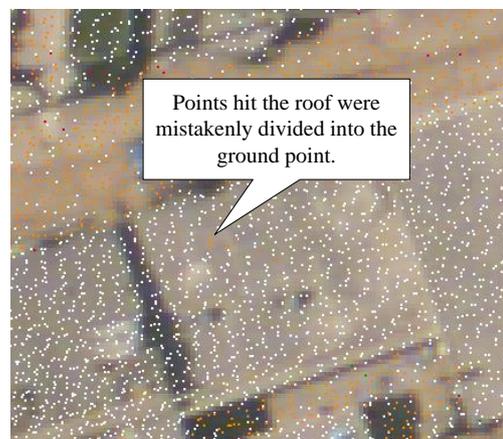


Figure 8. Orthogonal projection auxiliary filter.

V. EXPERIMENT AND ANALYSIS

The experiment has been conducted in the actual railway project and the results have been analyzed. Experimental area is located in Hunan Province, which has the rugged and complex terrain and most part belongs to the II, III-class terrain with dense vegetation assuming the high, middle and low multi-layered distribution. Besides, the railway in this area is about 450km and across the board. The data is collected by Leica ALS50 laser scanner and RCD digital camera. The scanning frequency is 90Hz. The pulse frequency is 150 KHz, and scan angle of 75 degrees. Moreover, the platform is

TABLE I.
ELEVATION PRECISION STATISTICS

Point Type	Amount	$\Delta \leq 0.1m$	$0.1 < \Delta \leq 0.2$	$0.2 < \Delta \leq 0.3$	$\Delta > 0.3m$	mean square error
Hard surface	200	148	49	2	1	0.092
Other elevation point	276	195	75	6	0	0.087
Leafy tree	68	39	24	3	2	0.147
Lawn in	130	67	50	11	2	0.136
Centre of Alignment	78	46	32	0	0	0.101
50m Outside the Alignment	102	98	4	0	0	0.041
No vegetation soft soil	50	8	29	6	7	0.212
Thick soft soil of weeds	31	31	0	0	0	0.039
Roadside grass	80	71	3	6	0	0.079

Yun-5 aircrafts. Taking into account the effects of vegetation to data acquisition, test points are obtained by repeating the flight in order to increase the density. The flying length is 2620 km and flying area is 1880km².

A. Accuracy Analysis

The DEM accuracy assessment in the railway applications takes the elevation points measured outside actually as reference. The accuracy calculation and statistics see the follow equations.

$$rms = \sqrt{\frac{\sum_{i=1}^n (H_i - H_0)^2}{n}} \quad (1)$$

rms – DEM elevation mean square error

n – checking point number

Hi – interpolation elevation by actual outside survey DEM

H0 – actual outside survey elevation

Through the Tab.1, we can conclude that: The mean square errors are all smaller than 0.2m, and most of them are smaller than 0.1m, excepting no vegetation and soft clay area whose mean square errors are bigger than 0.212m.

B. Economic Benefit Analysis

Using the LiDAR technique to measure railway, we can produce DEM with high accuracy, and greatly reduce the outside work, speed up production, decrease the cost. According to statistics, only the survey task between Chansha to Zhijiang period of Shanghai-Kunming railway is more than 400 kilometers. The LiDAR technique can decrease the 70% of the survey cycle, and reduce 30% of manpower, also lessen the environment pollution, and save the energy, achieving the effective environmental protection of railway survey.

VI. CONCLUSION

According to the Railway Survey and Design's characteristics and requirement, this paper proposes a feasible LiDAR data production process and method to generate DEM. Experience has proved that using LiDAR data for DEM generation can meet the needs of the present of large-scale railway survey and design, reduce field work, accelerate the production rate, save the cost of production and promote the efficiency of production. In the process of data acquisition and generation, we should have different way of process and selection according to the actual terrain and the different requirement, especially in soft soil of no vegetation or less vegetation, we need more measured points to correct and control LiDAR data to meet the standard precision. For most types of terrain, using the method proposed by this paper can meet the current demand for large-scale railway survey and design

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