# Application and Precision Analysis of Tree height Measurement with LiDAR


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**ABSTRACT**:

Light Detection And Ranging (LiDAR), is a system of laser detection and distance measurement installed on aircraft or satellites. Because of its high angular resolution, high range resolution and anti-jamming characters, the objects heights on the earth surface can be acquired precisely with LiDAR. In forestry application, LiDAR with spot size smaller than 1m can acquire thousands of laser points and has been applied to estimating the biomass parameters of trees. In this paper, the measuring method of tree heights, as one of the biomass parameters, with LiDAR especially for wooded areas is introduced. The relative tree heights comparative experiments at Changping district in Beijing are carried out to discuss the feasibility and the accuracy of tree height measurement with LiDAR based on the relative true value acquired by the total instrument. The main equipment, the measuring method and the experiments are detailed introduced.According to the experimental analysis, it is indicated that the overall accuracy meets the applicational requirement and the tree height measure method with LiDAR is feasible. But at the same time, there are gross errors and exceeding values exsiting in the measure results and the main reasons of them are lower density of point cloud and more aliased points. The research can provide reference for forestry biomass measurement.


## 1. INTRODUCTION

LiDAR (Shu N., 2005, Deng X. R. et al. 2005) integrating the laser distance measurement, Global Positioning System(GPS) and Inertial Navigation System(INS) three techniques, originally is designed to acquire high-precision Digital Surface Models(DSM)( Li Y. C. et al. 2002). At present, most of LiDAR can record multiple-echo data, generally at lest two-echo data and these echo data recorded contain the three-dimentional coordinate information representing the position of the top, side and bottom points of the surface features.

Because LiDAR has the particular characters of high angular resolution, high range resolution and anti-jamming etc., the object heights on the earth surface can be acquired precisely with LiDAR. Under the general terrain conditions, the planimetric accuracy of LiDAR is between 0.5m and 0.7m and the vertical accuracy can reach decimeter level. The points aquired by LiDAR are always dense and are usually figuratively called laser “point cloud”. In forestry application, small spot LiDAR is widely used with spot size smaller than 1m(Pang Y. et al, 2005) and for one tree, there are always tens to hundred of laser echo points, from which we can estimate the biomass parameters of the tree(Wu H. Y., et al. 2006, J.Holmegren et al.). Based on the references from home and abroad, this system has been succeeded in application in forestry.

In this paper, the method and principle of tree height measurement with LiDAR are introduced and based on comparative experiments and analysis, the feasibility and measurement precision with LiDAR is introduced in detail as follows.

## 2. LIDAR EQUIPMENT AND PROCESSING SOFTWARE

The LiDAR equipment used in this paper is ALTM3100 and four-echo data of point cloud are acquired by this equipment. The appearance of the equipment (quoted) is in Figure 1 and the main technical parameters are introduced as follow:

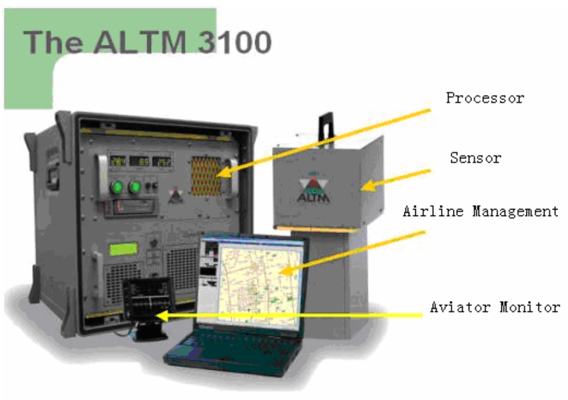



Figure 1. Appearance of ALTM 3100

- Flight Altitude:
  80 to 3500m
- Laser Impulse Frequency:
  33 kHz(the highest altitude 3500m )
  50 kHz(the highest altitude 2500m )
  70 kHz(the highest altitude 1700m )

100 kHz(the highest altitude 1100m )

- Bundle Radiation:
  Two radiation widths: one is 0.3m rad and the other is 0.8m rad.

- Laser Classification:
  IV level

The processing software is TerraScan and iLidar for point cloud measurement and classification, and TerraPhoto for image geometric correction. MatLab tools are adopted to analyze the measure results.

## 3. TREE HEIGHT MEASUREMENT METHOD WITH LIDAR

The flowchart of the tree height measure method with LiDAR is given in Figure 2.

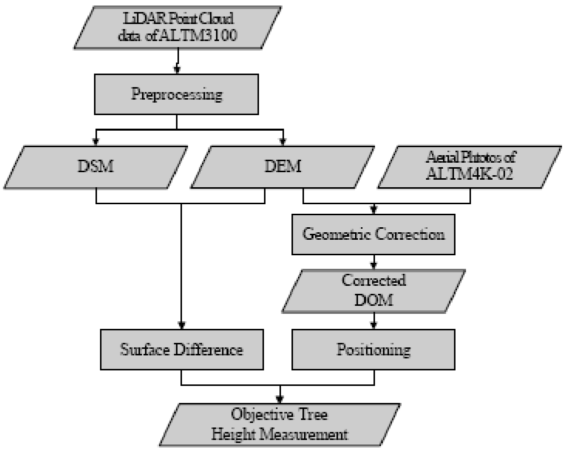



Figure 2. Flowchart of Tree Height Measure Method with LiDAR

Objective trees and surface terrain expressed by point cloud are shown in Figure 3.

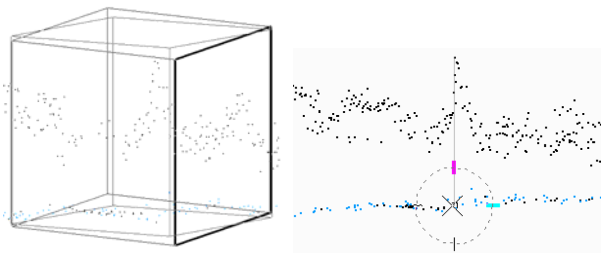


Figure 3. Objective Trees and Surface Terrain Expressed by Point Cloud

The surfaces of DSM and DEM are fit by the three-order spline curved surface(Zhou S.F., Li Z.Y. etc.,2007).

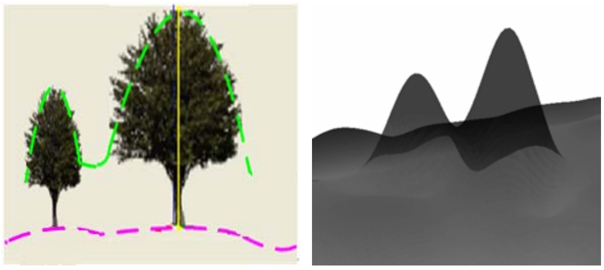


Figure 4. Fit DSM and DEM

- **Point Cloud Preprocessing**

The point cloud data are mainly processed by noise point removing and point classification. After these steps, the interesting points are extracted, some in the tree class and the others in the terrain class, then 0.1m Digital Surface Models (DSM) and 0.1m Digital Elevation Models (DEM) can be acquired by above software.

- **Aerial Photo geometric correction**

In order to locate the objective trees, the geometric correction of ALTM4K-02 digital true color photos synchronously acquired with LiDAR data has been performed to produce Digital Orthophoto Map (DOM). The corrected terrain reference is the DEM produced with LiDAR.

- **Objective Tree Height Measurement**

According to the corrected digital photos and the estimated height displacement values, the planimetric positions of the objective trees are calculated and the tree heights are measured by elevation difference of the points with the calculated planimetric positions on the DSM and DEM.

## 4. EXPERIMENTS AND ANALYSIS

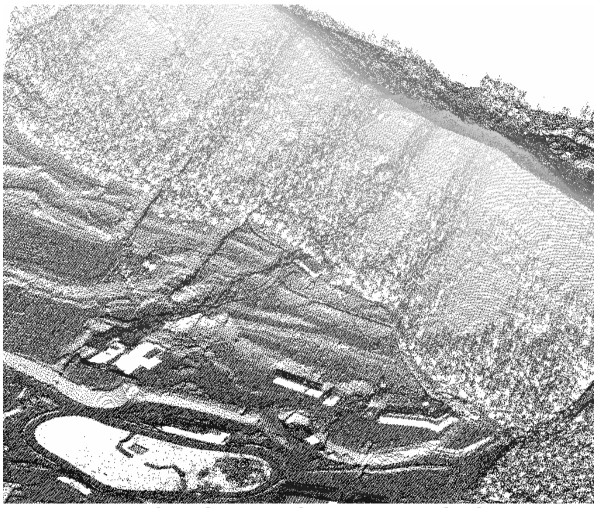
In order to analyze the accuracy of the tree height measure method with LiDAR, the trees heights measured by the total station instrument are acquired at the same time and these results are seen as the true values for experiments.

### 4.1 Experimental District

The experimental district is at the northwest of Changping in Beijing where there are many wooded areas and the three-dimensional results are acquired by iLidar software (Figure 4). According to image interpretation and outdoor identification, the main tree type of this district is cypress and the experimental wooded area is about 0.5hm$^2$. 37 trees in this district are chosen to be the test objective trees, which are labeled in Figure 5.

### 4.2 Experimental Results

The tree heights are measured both by indoor work with LiDAR and by field work with total station instrument. The serial numbers of the trees, tree heights measured by the both methods, the differences and the error tolerances are detailedly listed in the Table 1 And linear fit, quadratic fit and cubic fit are chosen to analyze the correlation between the results measured by LiDAR and by instrument.



a. Three-dimensional LiDAR Point Cloud

b. Three-dimensional LiDAR Point Cloud overlapped with DOM

Figure 4. Experimental District

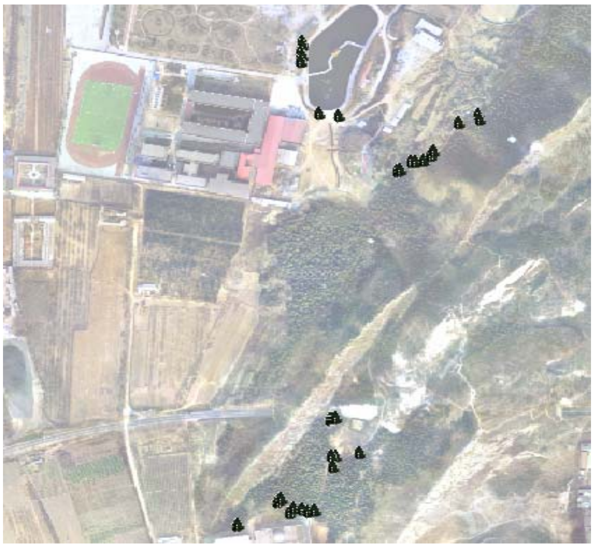


Figure 5. Distribution of the trees

| ID | Lidar /m | Real/m | Dif/m | 5%Limits/±m |
|---|---|---|---|---|
| 1 | 9.39 | 9.12 | -0.27 | 0.46 |
| 2 | 10.01 | 9.87 | -0.14 | 0.49 |
| 3 | 5.68 | 5.88 | 0.20 | 0.29 |
| 4 | 7.97 | 8.20 | 0.23 | 0.41 |
| 5 | 8.04 | 8.50 | 0.46 | 0.43 |
| 6 | 9.47 | 9.10 | -0.37 | 0.46 |
| 7 | 9.00 | 9.04 | 0.04 | 0.45 |
| 8 | 8.99 | 9.20 | 0.21 | 0.46 |
| 9 | 9.86 | 9.90 | 0.04 | 0.50 |
| 10 | 8.89 | 8.90 | 0.01 | 0.45 |
| 11 | 8.22 | 8.20 | -0.02 | 0.41 |
| 12 | 6.70 | 6.20 | -0.50 | 0.31 |
| 13 | 8.00 | 8.20 | 0.20 | 0.41 |
| 14 | 7.61 | 8.10 | 0.49 | 0.41 |
| 15 | 7.01 | 6.90 | -0.11 | 0.35 |
| 16 | 4.41 | 5.15 | 0.74 | 0.26 |
| 17 | 8.37 | 8.67 | 0.30 | 0.43 |
| 18 | 8.97 | 9.34 | 0.37 | 0.47 |
| 19 | 10.00 | 10.17 | 0.17 | 0.51 |
| 20 | 7.39 | 7.37 | -0.02 | 0.37 |
| 21 | 5.67 | 5.47 | -0.20 | 0.27 |
| 22 | 7.47 | 7.85 | 0.38 | 0.39 |
| 23 | 3.97 | 3.69 | -0.28 | 0.18 |
| 24 | 5.77 | 5.91 | 0.14 | 0.30 |
| 25 | 6.16 | 5.89 | -0.26 | 0.29 |
| 26 | 4.59 | 4.68 | 0.08 | 0.23 |
| 27 | 8.71 | 8.92 | 0.22 | 0.45 |
| 28 | 11.75 | 12.33 | 0.58 | 0.62 |
| 29 | 10.28 | 9.98 | -0.30 | 0.50 |
| 30 | 11.38 | 10.94 | -0.44 | 0.55 |
| 31 | 10.60 | 10.81 | 0.21 | 0.54 |
| 32 | 11.71 | 12.11 | 0.40 | 0.61 |
| 33 | 15.65 | 15.04 | -0.61 | 0.75 |
| 34 | 2.51 | 6.37 | 3.86 | 0.32 |
| 35 | 13.00 | 13.01 | 0.02 | 0.65 |
| 36 | 13.09 | 13.11 | 0.02 | 0.66 |
| 37 | 9.12 | 15.80 | 6.68 | 0.79 |

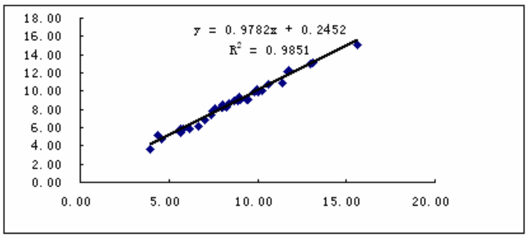
Table 1. Comparison of LiDAR Tree Height Measure results and those of Outwork with the Total Instrument

### 4.3 Experimental Analysis

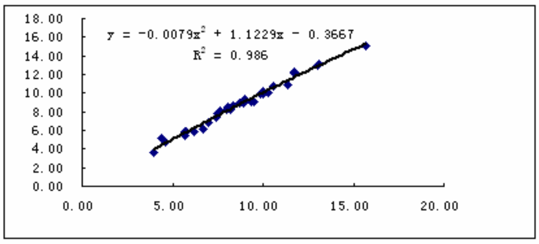
According to feasibility analysis, we get the conclusions as follow:

Firstly, the average tree height of LiDAR results and that of instrumental results are 8.68m and 8.76m separately. The average relative error is 0.913%, which meets the requirement of forestry investigation.

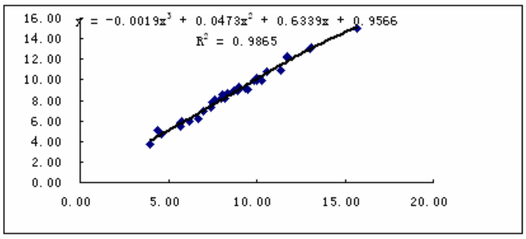
Secondly, the correlation factors of three fit methods(Han G. S. et al. 2005) are quite similar to each other and the values are all higher than 0.98(Figure 5), which indicates there is the obvious positive correlation between the results measured by LiDAR and by instrument. The correlation factor difference of either two fit methods is less than 0 .14%, so the linear fit can be chosen to be the final fit function between them.




a. Linear Polynomial




b. Second-order Polynomial




c. Third-order Polynomial

Figure 6. Three Fit Methods

Therefore, the tree height measuring method with LiDAR is feasible and can be applied to assisting field forestry investigation, especially for some difficult districts to measure tree heights.

The results measured by total instrument are seen as the true value and then the difference between the results measured with LiDAR and with instrument can be seen as the error. According to error analysis, we get the conclusions as follow:

Firstly, among the 37 trees, there are 35 trees whose errors are lower than 1m. The errors of the other 2 trees (No.34 and No.37) are higher than 3m and these results are considered as gross errors.

Secondly, among the 35 trees without gross errors, there are 30 trees whose errors are lower than the error tolerances, which are 5% of the true values of the objective trees, and the percent is 85.7%. The other 5 trees have errors higher than the error tolerances, and these results are considered as the exceeding values which are lower than 0.5m.

Tree heights measured with LiDAR have gross errors and exceeding values in the experiments. According to analysis, there are mainly two reasons:

Firstly, point cloud describing the objective trees is not enough(Liao L. Q. et al. 2004) and the relative density tends to be lower. For the trees which have sharp tops(J.Holmgren et al. 2003), points of the tree tops are not always acquired by LiDAR and then the DSM will not be snapped to the practical surfaces of the trees. In the experiments, the objective trees are cypresses and the exceeding values of 2 trees are caused by this reason.

Secondly, the aliased points around the objective trees are more and confusing when intervals among the trees are smaller or the trees are shorter. If there are more aliased points for one tree, it’s difficult to identify the top and the bottom of the tree, which will influence the location of the trees and generate the errors. In the experiments, the objective trees are in wooded area. The gross errors and the exceeding values of the other 3 trees are mainly caused by this reason.

## 5. CONCLUSIONS

LiDAR as a new developed active remote sensing technique has advantages of available acquisition and fast post processing of ground surface information, so it has potential application in forestry investigation. In this paper, a tree height measure method with LiDAR is discussed and the relative experiments are carried out. The experimental analysis indicates that the overall error meets the application requirement and the tree height measuring method with LiDAR is feasible. But at the same time, there are gross errors and exceeding values exsiting in the measure results and the main reasons of them are lower density of point cloud and more aliased points. The research can provide reference for forestry biomass measurement.

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