Journal of Electronics and Information Science (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/jeis.2023.080203
ISSN 2371-9524 Vol. 8 Num. 2

Optimization Classification Research Based on Laser Scanning Point Cloud Reflectance Intensity Correction

Wenchao He, Chenghui Wan*, Yang Cheng, Ruifan Li, Jundi Zhang

School of Hydraulic and Ecological Engineering, Nanchang Institute of Technology, Nanchang, Jiangxi, 330099, China
**Corresponding author*

Keywords: Laser intensity, 3D terrestrial laser scanning, point cloud normal vector estimation, point cloud classification

Abstract: The laser intensity information of 3D terrestrial laser scanning point cloud is very important for target classification, but the effect of classification is not ideal because of the influence of reflection material, incident angle and distance. In this paper, the intensity of point cloud is obtained by scanning the experimental wall surface with a 3D terrestrial laser scanning. By using the method of comparative analysis, the normal vector of point cloud is estimated by using k-nearest neighbor points on the wall surface for each area, and the laser scanning incidence angle is calculated. The influence of reflection material, incident angle and distance on laser intensity is analyzed by regression. Through the polynomial regression analysis of scanning distance and laser intensity, the optimized parameters are obtained to correct the laser intensity, and the corrected laser intensity is used to classify the point cloud. The results show that the point cloud laser intensity can be corrected according to the polynomial regression analysis of laser ranging data, and the corrected point cloud laser intensity has a good classification effect.

1. Introduction

3D Terrestrial Laser Scanning (TLS) plays an important role in the protection of cultural relics and historic sites [1]. The scanned point cloud data includes the 3D coordinate information (X, Y, Z) and attribute information of the object. The attribute information can be divided into point cloud color information (RGB) and Laser Intensity I. The point cloud data needs to classify the scanned laser point cloud into different types of ground objects [2]. The point cloud classification algorithm is mainly based on the geometric information of point cloud to realize the denoising and classification of point cloud [3]. Song [4] and Coren [5] used the intensity information of point cloud to classify ground objects, and proved the feasibility of using intensity information to classify ground objects; Li Jian [6] proposed a deep neural network algorithm based on multi-scale spherical neighborhood characteristics; Zhao Xiaoxiang [7] proposed a method for detecting trees in parks based on point cloud intensity; Cai Yue [8] studied the influence of various factors and their interaction on the number of point clouds, the laser intensity of point clouds and the standard deviation of point clouds; Xia Guofang [9] et al. studied the influence of laser incident angle on point cloud laser intensity. The influence of distance on the accuracy of ground laser scanning is studied by Yang Meijie; Tan Kai [10] theoretically deduced the influencing factors of laser intensity value and proposed a correction method of intensity value. The laser intensity values further investigate the laser intensity influencing factors and characteristics, which can provide more solutions for the classification of point clouds.

However, the laser intensity is affected by many factors, and the phenomenon of "homogeneous but different spectrum, same spectrum but not homogeneous" will appear, so the measured values cannot be directly applied to point cloud classification. In this paper, by scanning the building wall, mainly using the corresponding incident angle and laser ranging value to correct and classify the point cloud laser intensity, verify the feasibility of point cloud laser intensity classification, and use laser intensity to extract and classify buildings.

2. Principle of TLS Laser Intensity Correction

2.1. Influence Factors of Laser Intensity

The laser intensity value of 3D terrestrial laser scanning point cloud is mainly affected by system variables and target variables. The system variables include laser ranging value, laser incident angle, atmospheric attenuation, signal processing and so on; target variables mainly include target reflectivity, target roughness, target size and target inclination [9]. For close-up 3D terrestrial laser scanning, the lidar equation can be simplified to

$$\mathrm{I} = f(\rho, R, \theta, P_E) = \mathrm{C}\frac{P_E \rho cos\theta}{R^2}\eta_{Sys} \tag{1}$$

Where, ρ is the average reflectivity of scanning target, R is the laser ranging value, θ is the incident angle, P_E is the laser emission power, I is the laser intensity value, η_{Sys} is the transmission coefficient of laser radar optical system, and C is the system constant.

In this paper, Riegl VZ-1000 3D laser scanner is used to obtain the geometric and physical information of wall point cloud data. The laser emission power during scanning P_E is a constant value, ρ can be regarded as approximately consistent, and the transmission coefficient of optical system is regarded as a constant, so the formula can be further simplified as:

$$\mathrm{I} = f(\rho, R, \theta) = C' \ \frac{\rho cos\theta}{R^2} \tag{2}$$

2.2. K-Nearest Neighbor Point Estimation of Point Cloud Normal Vector

The k-nearest neighbor point estimation point cloud normal vector algorithm is to fit all points in the neighborhood of any point into a plane, and calculate the normal vector of the plane to estimate the normal vector of the point, with the following method: Given a set of points $p_i = \{p_1, p_2, p_3 \cdots p_n,\}(i \geq 3)$, set the search radius R and find a plane S that minimizes the sum of the squares of the distances from all points to the plane.

According to the plane general formula:

$$Ax + By + Cz + D = 0 \tag{3}$$

Assume that the planes of the point sets S_i are parallel to each other, and obtain the objective function:

$$MIN = \sum_{i=1}^{n}(Ax_i + By_i + Cz_i + D)^2 = 0 \tag{4}$$

It satisfies $\frac{\partial MIN}{\partial x_i}$=0, $\frac{\partial MIN}{\partial y_i}$=0, $\frac{\partial MIN}{\partial z_i}$=0. A system of linear equations is obtained:

$$\sum_{i=1}^{n}(Ax_i + By_i + Cz_i + D) = 0 \tag{5}$$

In this paper, a smooth wall surface is selected for experiment. For any point p of scanned point cloud data, K nearest adjacent points can be searched by setting search radius and maximum number of neighborhood points, and then the optimal plane solution of the neighborhood is fitted by RANSAC algorithm, and the normal vector (A, B, C) of the plane point is obtained, as shown in Figure 1. Figure 2 shows that the normal vector obtained by the method may have opposite directions, and the normal vector needs to be processed reversely.

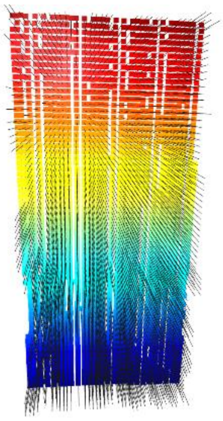


Figure 1: Point Cloud Normal Vector Front

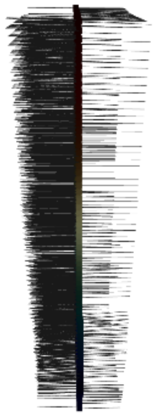


Figure 2 Point Cloud Normal Vector Side

2.3. Laser Incident Angle Correction

The laser incident angle is the angle between the emitted laser beam and the target point normal vector. The incident angle directly affects the laser spot size and echo signal intensity on the target surface. The incident angle θ can be obtained according to the coordinates of the point cloud (X, Y, Z) and the estimated value of its normal vector (A, B, C):

$$\theta = \arccos\frac{(X,Y,Z)\cdot(A,B,C)}{\mathrm{R}^{'}} \tag{6}$$

It can be seen from Equation (2) that for the expanded Lambertian object, the intensity value is proportional to the cosine value of the incident angle, i.e., $I \propto cos\theta$. Correction of the intensity value affected by the incident angle:

$$I_N = \frac{I}{cos\theta} \tag{7}$$

Where, I_N is the correction value of laser intensity, $cos\theta$ is the cosine value of laser incident angle, and I is the laser intensity value measured by 3D laser scanner.

2.4. Correction of Laser Ranging Values by Polynomial Regression Model

The 3D coordinates (X, Y, Z) and intensity values I of the point clouds are scanned, and the acquired point cloud data are pre-processed with RISCAN PRO software for point cloud denoising, etc. to obtain the experimental point cloud data. Solve for the actual distance $R^{'}$ from the scanner to the point cloud as follows:

$$R^{'} = \sqrt{X^2 + Y^2 + (Z - \hbar_i)^2} \tag{8}$$

Where, R' is the laser ranging value, X, Y, Z are the 3D coordinate of the point cloud data, and $\hbar_i$ is the instrument height.

According to the lidar ranging equation, the point cloud intensity as a function of distance $I = f(R)$ can be regarded as a derivable continuous function and is nonlinear, and a higher-order polynomial can be considered to curve-fit it.

$$I = (A_1R^3 + B_1R^2 + C_1R + D_1)f(\theta) \tag{9}$$

Where, I is the original laser intensity value, R is the laser ranging value, A_1, B_1, C_1, D_1 are polynomial parameters, and $f(\theta)$ is a function of the laser incidence angle θ. Correcting the laser intensity values according to the determined polynomial parameters and the laser ranging values:

$$I_N = I \cdot \frac{1}{cos\theta \cdot (AR^3+BR^2+CR+D)} \tag{10}$$

2.5. Unified Correction Model of Laser Intensity

Combined with the correction formula of laser incident angle and laser ranging value to laser intensity, the unified correction model of the two factors can be obtained as follows.

$$I_N = \frac{I}{(A_1R^3+B_1R^2+C_1R+D_1)} \tag{11}$$

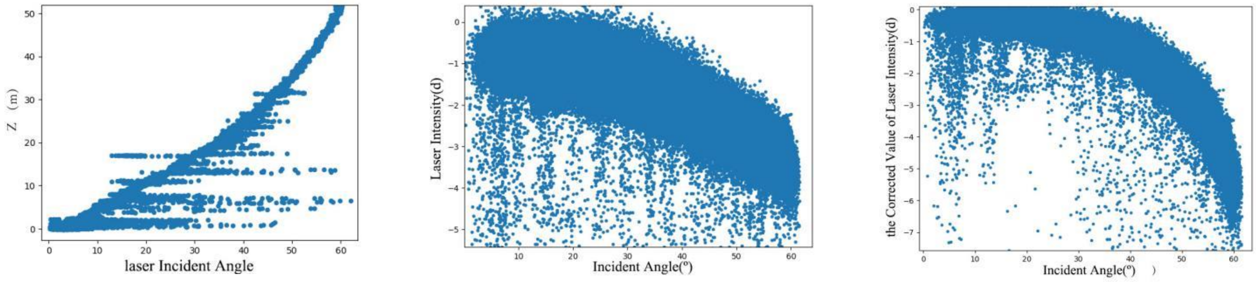
Equation (13) shows that the corrected laser intensity value is only affected by the target variable, and the point cloud data can be classified by the corrected laser intensity value by reasonably dividing the range of the laser intensity value.

3. Point Cloud Intensity Correction Experiment

RIEGL VZ-1000 3D laser scanner was used for the experiment. The white whitewashed wall was selected as the experimental object. The data are collected at intervals of 5 m, 10 m, 15 m, 20 m, 25 m and 30 m when the instrument is facing the experimental wall. The surface of the wall is smooth and unstained, and the strength correction experiment is carried out in the zonal region.

3.1. Analysis of Point Cloud Intensity at Incident Angle

As shown in Figure 3(a), the incident angle is proportional to the target height. Figure 3(b) shows the relationship between incident angle and laser intensity. In this paper, a rectangular area from the bottom of the building to the top of the building (the number of point clouds is 233,743) is selected, and the laser intensity after the ranging value is corrected is the y-axis, and the reflection angle is the x-axis. Figure 3(b) shows the relationship between the incident angle and the laser intensity without the ranging correction, and it can be seen that the range of the laser intensity is wider when the incident angle is the same. After ranging correction in Figure 3(c), the laser intensity value is more concentrated when the incident angle is the same, which means that the laser intensity value after ranging correction is more affected by the incident angle and is inversely proportional to the incident angle. The larger the incident angle is, the smaller the laser intensity value is.



(a) laser Incident Angle Distribution

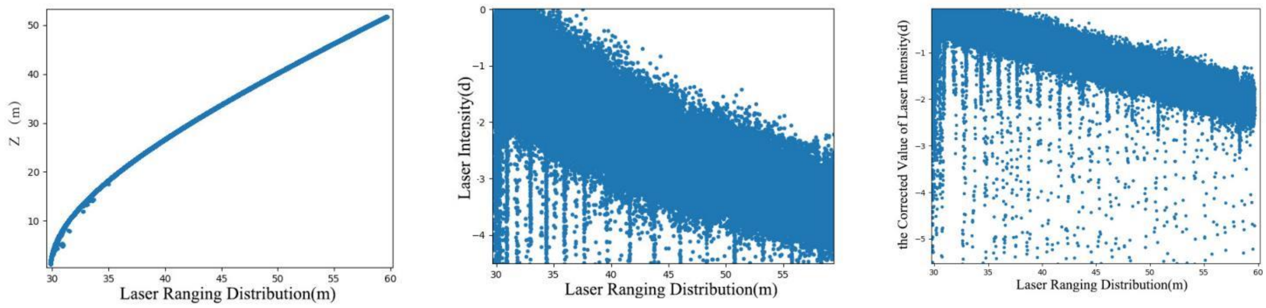
(b) The Relationship between Incident Angle and Laser Intensity

(c) The Relationship between the Incident Angle and the Corrected Value of Laser Intensity

Figure 3: Incident Angle Point Cloud Data

3.2. Distance Point Cloud Intensity Analysis

The distribution law of laser intensity and laser ranging value is analyzed by selecting the area with large range of laser ranging value and uniform material. As shown in Figure 4, both the laser range and the incident angle increase with height. Make incident angle correction on the laser intensity according to Equation (10), and draw the scatter diagram of the relationship between laser ranging value and laser intensity after correction, as shown in Figure 4(c). When the laser ranging value is the same, the range of laser intensity is wider. After the correction of incident angle, the laser intensity value is more concentrated and the overall laser intensity increases when the laser ranging value is the same, which shows that the laser intensity value after the correction of incident angle is more affected by the laser ranging value and is inversely proportional to the laser ranging value. The larger the incident angle is, the smaller the laser intensity value is, and the downward trend is slower than that of the incident angle.



(a) Laser Ranging Distribution

(b) The Relationship between Laser Intensity and Ranging

(c) The Relationship between Laser Intensity Angle Correction Value and Ranging

Figure 4: Distance Point Cloud Data

3.3. Unified Correction Model of Point Cloud Laser Intensity

Without considering the influence of other parameter variables on the laser intensity, the ranging value and incident angle correction are carried out on the point cloud laser intensity. According to Formula (2), it can be seen that: the corrected laser intensity is mainly affected by the target variable, and the corrected laser intensity is constant if the target material is the same, which can provide a classification basis for automatic classification of point clouds.

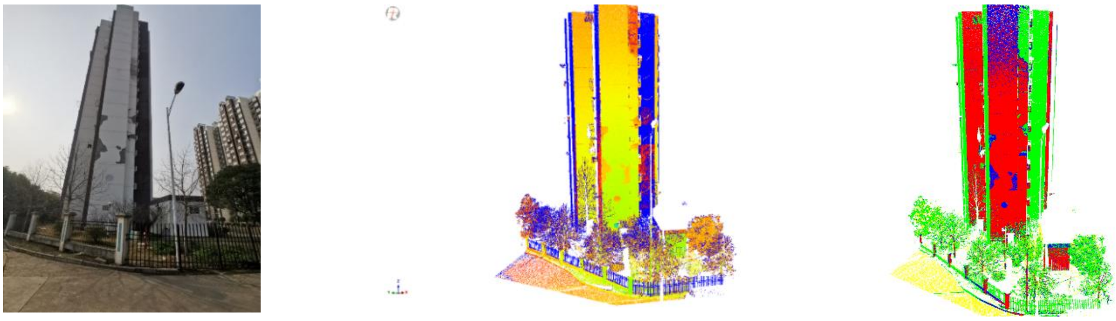
4. Case Analysis

Using the same experimental equipment, the point cloud data of the apartment exterior wall with partial paint peeling were scanned and collected. The wall height is about 50 m, and the facing wall width is 10 m. The wall is divided into uniform rectangular areas by lines, and the material distribution of each area is uniform as shown in Figure 5(a). Two stations are set up around it: one point is facing the scanning wall, and one point is set up at a certain horizontal angle with the wall. The point cloud of a large area (the quantity is 1,348,761) is extracted and classified, and the area containing trees, railings, walls and ground is selected for full correction of the laser intensity value, and the laser intensity interval of the corrected value is [0-30], and the interval is divided for several times until the objects of various materials can be distinguished and the spatial 3D coordinate data of the corresponding interval is extracted, and the features of the scanned data of the interval are extracted. The original 3D scanned point cloud intensity of the selected area is shown in Figure 5(b). All point clouds in this area are corrected for incident angle and distance by using laser intensity unified correction model, and the laser intensity distribution is shown in Table 1.

Table 1: Reflected Intensity Distribution

Corrected Point Cloud Intensity	(0,1]	(1,2]	(2,3]	(3,4]	(4,5]	(5,6]	(6,7]	(7,8]	(8,9]	(9,10]
Number of Point Clouds	505779	251463	188655	60010	33877	23261	16036	12311	9940	9864

Where, the number of wall surface point clouds is 645,048, which is mainly concentrated in the [0-2] interval; as the wall surface of the scanning data has two types of gray paint and white paint, the corrected point cloud data can be classified by a method of adjusting the laser intensity interval values for a plurality of times to obtain laser intensity intervals of different materials with reasonable intensity distribution, Figure 5(c) is the interval distribution diagram of the obtained wall surface correction value.



(a) Apartment Scan Overview (b) 3D Scanning of Apartments (c) Interval Distribution of Wall Correction Value

Figure 5: Scanning of Apartment

5. Conclusions

The 3D laser scanning technology is an important 3D geospatial data acquisition technology, using the laser intensity of the laser scanning point cloud for building target classification has a certain role, the point cloud laser intensity information for correction processing, through the regression correction parameter adjustment of the incident angle and reflection distance, to obtain a relatively reasonable laser intensity interval of different materials, point cloud classification extraction of buildings, has important value in the smart city, 3D reconstruction, heritage conservation and other aspects.

Acknowledgements

Jiangxi Province Student Innovation Project "BIM+LIDRA Technology-Based Digital Heritage Technology for Ancient Buildings" (202211319005).

References

[1] Yang Bisheng, Liang Fuxun, Huang Ronggang. Research progress, challenges and trends of 3D laser scanning point cloud data processing. Journal of Geodesy and Geoinformation Science, 2017, 46(10): 1509-1516.
[2] Tan Kai, Cheng Xiaojun. Adaptive Unsupervised Classification of Terrestrial Laser Point Clouds Based on Intensity Data. Laser & Optoelectronics Progress, 2016, 53(03): 240-246.
[3] Wu Yonghua, Hu Yihua, Gu Youlin, Wang Enhong. Discussion and Prospect of Laser Point Cloud Classification Algorithm. Papers of the 9th National Optoelectronic Technology Academic Exchange Conference (Volume I), 2010: 152-156.
[4] Song J.H., Han S.H., Yu K., eta. Assessing the possibility of landcover classification using lidar intensity data. International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences, 2012, 34(3/B): 259-262.
[5] Coren F., Sterzai P. Radiometric correction in laser scanning. International Journal of Remote Sensing, 2006, 27 (15): 3097-3104.
[6] Li Jian, Yao Liang. Terrestrial Laser Point Cloud Semantic Segmentation Based on Multi-Feature Depth Learning. Science of Surveying and Mapping, 2021, 46(03): 133-139+162.
[7] Zhao Xiaoxiang, Huang Liang. Park Arbor Detection Method Based on Point Cloud Intensity. Beijing Surveying and Mapping, 2020, 34(03): 292-295.
[8] Cai Yue, Xu Wenbing, Liang Dan, Li Chong, Chen Zuo. The Influence of Different Factors on the Precision of Terrestrial 3D Laser Scanning Point Cloud. Laser & Optoelectronics Progress, 2017, 54(09): 364-373.
[9] Xia Guofang, Hu Chunmei, Cao Bizheng, Li Tianshuo. Study on the Effect of Laser Incident Angle on the laser intensity of Point Cloud. Laser Journal, 2016, 37(04): 11-13.
[10] Tan Kai, Cheng Xiaojun. Influencing Factors and Correction Methods of Laser Intensity Values in Terrestrial Laser Scanning. Science of Surveying and Mapping, 2014, 39(09): 98-101+120. DOI: 10.16251/j.cnki. 1009-2307. 2014.09.019.