Accuracy Analysis of A Ground-Based LIDAR Data Set for 3-D Building Model

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Abstract: The 3-D coordinates of point cloud produced by a ground based LIDAR are usually, combined with their corresponding gray level values, and processed to generate a 3-D model. Generally, a building is scanned in a multi-viewpoint way, and the resulted data sets are joined together to generate a complete 3-D model. When a 3-D model produced in such way, one should consider its accuracy and precision.

In this research, a building has been scanned in multi-viewpoint way using a ground based LIDAR. Point cloud data set was then transformed into a CAD environment for deriving the space coordinates of the building's feature points. The building was also surveyed using a GPS based total station. Two sets of space coordinates of the building's feature points could be compared and analyzed. This will be helpful to evaluate the fidelity of the whole LIDAR data set.

Keyword LIDAR, Point Cloud, CAD, 3-D Building Model

1. Introduction

Ground-based LIDAR has been used for scanning object widely. However, it is hard to find any information of geometry from point cloud directly. Besides, scanned data is usually combined from various stations, and is shown by 3-D model. Generally, the progress of combine use coordinates transformation between different stations. Therefore, the error propagates unavoidably, from one coordinate system to the other.

In fact, the geometry information from points cloud can be extracted by using the distribution property of LIDAR points. In this research, the accuracy of feature points was analyzed by using its relationship of geometry. The error transferred from one model to the second model has been observed when combining different point clouds.

2. The basic theory

The extraction of geometry components, the coordinate systems of LIDAR and LIDAR points, and the coordinate transformation of different system, are described in sequence as follows.

1) The extraction of geometry components

Usually, LIDAR points are not located in objects' feature points fortuitously. When laser scanning object's boundary or feature points, the boundary of point cloud may stretch or narrow somehow. However, the feature points could be defined by using some geometric characteristics. In general, three kinds of feature points could be located, the intersection of lines, the intersection of lines and planes, and the intersection of three planes.

In this study, the intersection of three planes was used to define the feature point. The three planes are computed firstly. The plane formula is shown as follows:

$$ax + by + cz = d \tag{1}$$

In the Eq. (1), x, y, and z, are coordinates of LIDAR point, a, b, c, and d, are coefficient. This formula can be rewritten as follows:

$$ax + by - d = - cz$$

or

$$(a/c)\, x + (b/c)\, y - (d/c) = -z \tag{2}$$

$$a'x + b'y - c' = -z \tag{3}$$

a', b', and c' are computed by using least squares.

Three planes for any feature point may be derived as follows:

$$\begin{aligned} a'x + b'y + z &= c' \\ a''x + b''y + z &= c'' \\ a'''x + b'''y + z &= c''' \end{aligned} \tag{4}$$

A simultaneous solution of Eq.(4) can obtain the 3D coordinates of the feature point.

2) The coordinate systems of LIDAR and LIDAR points

LIDAR center is used as the origin of the coordinates in this study. According to the right-hand rule, the direction of the thumb is defined as the x-axis, the index, or the depth of field is defined as the y-axis, the middle figure, or the zenith is defined as the z-axis.

Assume a vector IP directs from LIDAR center to LIDAR point. S, α, and β are slope-distance, azimuth, and vertical angle of the vector IP respectively. The 3D coordinates of a LIDAR point can be defined as follows:

$$\begin{aligned} X &= S\times \cos\beta \times \sin\alpha \\ Y &= S\times \cos\beta \times \cos\alpha \\ Z &= S\times \sin\beta \end{aligned} \tag{5}$$

3) The coordinate transformation of different system

The maximum range of the study area is less than 100m. The effect of the Earth curvature can therefore, be ignored. Assume that the 3-D coordinates of a LIDAR center are x_1, y_1, and z_1 respectively. And the 3-D coordinates of another LIDAR center are x_2, y_2, and z_2 respectively. The coordinate transformation formula of the two systems can be derived as follows:

$$\begin{aligned} x_2 &= ax_1 - by_1 + c \\ y_2 &= bx_1 + ay_1 + d \end{aligned} \tag{6}$$

$$z_2 = z_1 + e$$

It needs only two common points to obtain the coefficients. If there are more than two common points, least squares solution can be used.

3. Experiment design and data processing

1) Feature points

In this study, sections A and B of a high building were scanned and shown in Figures 1 and 2 respectively. In section A, scanned distance is around 25m, and 20 feature points were chosen. In section B, scanned distance is around 100m, and 25 feature points were chosen. Corners formed by walls and windows could be recognized obviously. They have then, been selected as feature points.

Figure 1 (Section A)

Figure 2 (Section B)

2) Computation of the feature points' coordinates

As stated before, any feature point was defined as the intersection of three planes. When computing the plane, at least 20 LIDAR points have been selected. The LIDAR points are near to their corresponding feature point.

Least squares and iterative procedure techniques were used to compute the plane equation. Root mean squares error (RMSE) of any plane was also evaluated. If RMSE exceeds a threshold value, a LIDAR point with the maximum residual is eliminated. The plane equation is computed again. The procedure above is executed continuously until the RMSE is small enough.

When three planes of a feature point are determined, the intersection of the three planes is solved using Eq.(4).

3) Coordinate transformation

When scanning the building, sections A and B have their own coordinate systems individually. For integrating the coordinate systems, Coordinates of section A should be transformed to coordinates of section B, or coordinates of section B should be transformed to coordinates of section A. Both of two transformations were completed in this study. Five common points and least squares were used to compute the transformation coefficients.

4) Ground observation

3-D coordinates of the feature points were also measured by using a Leica Smartstation instrument. The instrument has GPS function. Therefore, 3-D ground coordinates of stations could be positioned by using RTK GPS with enough accuracy.

5) Comparison of two coordinates of feature points

As described above, each feature point has two kinds of 3-D coordinates. The first 3-D coordinates were computed by using Eq. (4). These coordinates were originally, determined by LIDAR's observation. The second one was 3-D coordinates measured in ground. For comparing the two coordinates, coordinate transformation from one to the other was completed and analyzed.

4. Data analysis

1) Section A and Section B have their LIDAR coordinate systems individually

Table 1 shows the experiment results. In Table 1, "Before" means that points have not been transformed, "After" means that points have been transformed. The P-RMSEs of these two sections are around 0.05 m. In Figure 3, the errors have normal distributed appearance.

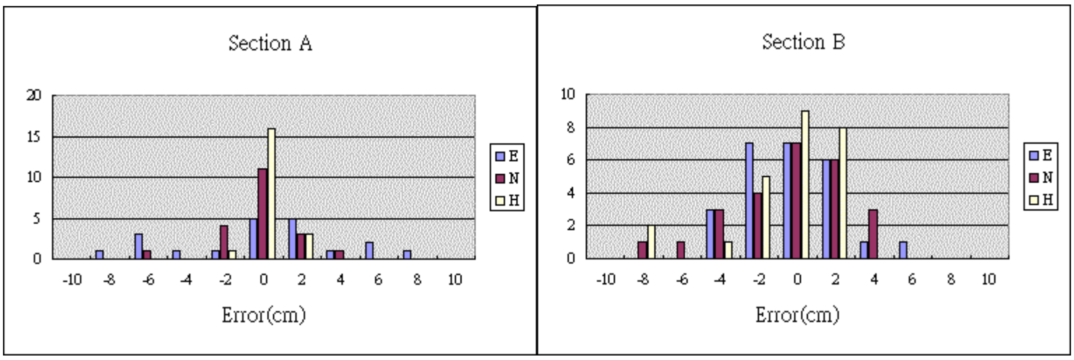

Figure 3

Table 1(Unit: m)

Section A	E-RMSE	N-RMSE	H-RMSE	P-RMSE
Before	0.045	0.019	0.010	0.050
After	0.048	0.048	0.040	0.079
Section B	E-RMSE	N-RMSE	H-RMSE	P-RMSE
Before	0.026	0.034	0.028	0.052
After	0.086	0.083	0.045	0.128

2) Section A and Section B have a unique LIDAR coordinate system

As shown in Table 2, the P-RMSE is 0.051m without transformation, and the P-RMSEs are 0.101m and 0.065m respectively with transformation. In Figure 4, "Coordinate system C" means that coordinates obtained from LIDAR's observation were compared with ground coordinates system directly. "Coordinate system A" means that all feature points are located in section A's coordinates system, and "Coordinates system B" means that all feature points are located in section B's coordinates system.

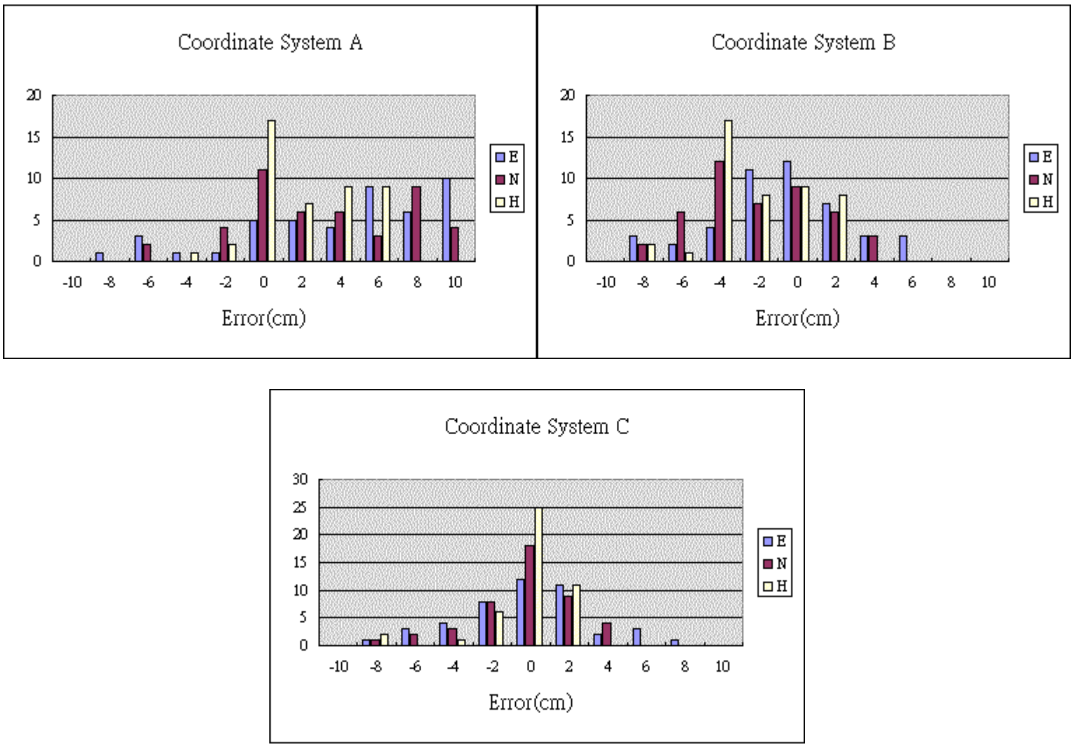

Figure 4

Table 2(Unit: m)

Unit: m	E-RMSE	N-RMSE	H-RMSE	P-RMSE
Coordinate System A	0.071	0.063	0.034	0.101
Coordinate System B	0.037	0.041	0.034	0.065
Coordinate System C	0.036	0.029	0.022	0.051

5. Summary

1) As indicated above, the method of determining the feature points by three planes seems to be feasible and reasonable.

2) If the LIDAR points could be recognized apparently in the scanned image, the distance between LIDAR and object seems not to affect the accuracy of positioning much more.

3) A unique coordinate system should be the best for the whole sections. However, when transforming coordinate from one section to the other one, error propagation has to keep in mind.

4) When sampling the LIDAR points, number of points and distributed way still need further research.

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