Research on Building Measurement Accuracy Verification Based on Terrestrial 3D Laser Scanner

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Abstract. The accuracy of terrestrial 3D laser scanners is mainly determined by the accuracy of ranging and angle measurement. Therefore, the research of horizontal angle accuracy is very important. The current construction industry can develop at the fastest speed because of the advent of many advanced science and technology research and development. The rational application of these science and technology to the construction industry can intuitively display the internal structure and external shape of the building. In front of people, it effectively guarantees the country's economic benefits and the people's property safety. The article studies the influence of distance, incident angle and target color on the accuracy of the scanner during measurement. Using the plane fitting method to analyse the accuracy, a qualitative analysis conclusion is drawn that as the distance increases, the angle of incidence increases, which will cause the measurement accuracy of the ground 3D laser scanner to decrease.

1. Introduction
With the widespread application of terrestrial 3D laser scanning technology in various fields, the requirements for instrument accuracy are getting higher and higher, so it is particularly necessary to check and calibrate the instrument accuracy. The data obtained by the laser scanner is a point cloud composed of discrete three-dimensional points. Each pixel of the point cloud contains a distance value and an angle value. The point cloud data obtained by the 3D laser scanning technology can reach the sampling interval of millimetres, so that the laser scanning technology can be applied to the fields of engineering surveying, ancient buildings and cultural relics protection, digital cities, and there are many successful examples. Ground-based 3D laser scanners are late in appearance and complicated in structure. There is no unified standard and specification for how to evaluate the performance of instruments from different manufacturers. Literature [1] uses the six-segment analytical method and indirect adjustment method to calibrate the range and angle of the ground 3D laser scanner; Literature [2] uses the average modulation on transfer function (AMTF) model to measure the angle of the point cloud the resolution was evaluated for accuracy. To evaluate the accuracy of terrestrial 3D laser scanners, it is necessary to understand the composition of accuracy. The accuracy of the measurement results of the terrestrial 3D laser scanner is mainly affected by the angle measurement accuracy, distance measurement accuracy, resolution, edge effects, reflection characteristics of the measurement object, environmental conditions and later data processing methods. Among them, the angle and distance measurement accuracy are the main factors that affect the accuracy of the measurement results. Therefore, in order to analyse the influence of the above factors on the final accuracy, the ground 3D laser scanner was selected as the experimental instr
ument for remote ranging, and the impact on the final accuracy with the difference of distance, incident angle, and target color was studied and analysed. The relationship among them.

2. Experimental principle and experimental design

2.1. Basic principles of instrument calibration
The 3D laser scanner, like the total station, is a three-axis system composed of horizontal axis, vertical axis and collimation axis. When the three-dimensional laser scanner is working, the laser is directed by the transmitter to the refracting prism, and the prism is refracted to the measured target, and the scanning angle value is obtained by accurately positioning the rotation step of the laser scanner.

2.2. Drawing up the scanning plan
Fine modeling needs to accurately express the geometry of the object. The scanning resolution of the point cloud is the key factor that determines the fineness of the model, and the accuracy of the model is mainly affected by the scanning error. Therefore, the appropriate scanner should be selected according to the scanner index parameters and the actual situation of the building, and the best scanning route should be planned, and the station location and number of stations should be initially determined. Since the shape of the building is relatively regular, it is not required to collect all corners of the building when considering the establishment of the station. It is only necessary to ensure that the outline and characteristic lines of the target object are obtained. In addition, it should be determined whether to unify the model to the geodetic coordinate system based on research or production needs. If necessary, the geodetic coordinates of more than 3 control points should be determined before scanning to facilitate the conversion of later results [3].

2.3. Field data collection
Field data acquisition includes point cloud data acquisition and texture image acquisition. The point cloud data is used to construct the geometric model of the building and accurately express the orientation of the building. Texture images are used for object surface image mapping to make geometric models more realistic. For point cloud data acquisition, when a high-precision scanner is used for data acquisition, the scanning accuracy will decrease as the distance increases. If the site is far away from the target building, the point cloud obtained will be sparse, which cannot meet the modeling requirements. Conversely, the denser the point cloud, the higher the scanning accuracy, which increases the burden on point cloud storage, display and data processing. Therefore, the best scanning resolution of each station should be selected individually according to the specific situation before performing the scanning. Fine and realistic models not only require high-precision point cloud data, but also corresponding high-definition texture images. In order to meet the needs of texture mapping in the later stage, care should be taken to avoid the loss of color, contrast and other information when taking pictures of the sky during texture collection. The detailed process is shown in Figure 1 [4].
2.4. Data processing and model establishment

Data processing mainly includes processes such as noise removal, data registration and splicing, and data elimination. 1) Noise removal. In the actual scanning process, due to the influence of environmental and human factors, the acquired point cloud data inevitably contains noise. In order to reduce or eliminate the influence of noise on the modeling quality, the data must be denoised. 2) Data registration and splicing. Affected by the complexity of the scanned object and surrounding obstructions, scanning operations often require multiple stations and multiple angles. Data registration and splicing are to transform data in different coordinate systems into a unified coordinate system through coordinate transformation, and splice the point cloud data scanned by different stations into a data file [5]. 3) Eliminate data redundancy. After the cloud data of each station is spliced, repeated sampling points in the scanning overlap area will cause data redundancy problems. Without affecting the quality of modeling, it is necessary and necessary to reduce these redundant data. The three-dimensional surface model of the object is established using the point cloud data of the scanned object surface obtained after data processing, which is mainly composed of the process of feature line extraction and three-dimensional model establishment.

The coordinate system used by the 3D laser scanner is the station centre coordinate system with the instrument centre as the origin of the coordinate. After extracting the target point coordinates from the 3D laser scanning point cloud data, the horizontal angle φ can be calculated for 3 scans. And the vertical angle α, and record it in the table, where (x, y, z) is the three-dimensional coordinate value of the target point in the coordinate system of the three-dimensional laser scanner.

$$\varphi = \arctan \left( \frac{y}{x} \right)$$  \hspace{1cm} (1)

$$\alpha = \arctan \left( \frac{z}{\sqrt{x^2 + y^2}} \right)$$  \hspace{1cm} (2)
At the same time, the model operation data results of 30 m measurement data are compared with the program operation data results for program verification. First, the observation value equation is listed

\[ \bar{\phi}_i = \phi_i + \nu_i + c_i + i_i \]  \hspace{1cm} (3)

In the formula, \(\bar{\phi}_i\) is the true value of the horizontal scanning angle; \(\phi_i\) is the approximate value of the scanning horizontal angle of the 3D laser scanner; \(\nu_i\) is the angle observation correction number; \(c_i = \frac{c}{\tan \alpha}\) is the error of the laser not perpendicular to the rotation axis of the scanning prism; \(i_i = \tan \alpha\) is the tilt error of the prism rotation axis. Written as error equation

\[ V = B X - L \]

\(\sum_{i=1}^{n} \sum_{j=1}^{m} \text{poly data} \)  \hspace{1cm} (4)

3. Analysis of test results

3.1. Close-range plane fitting results

In order to reduce the influence of the system error on the test results, it is necessary to perform a plane fitting on the test metal plate in the room to verify the flatness of the plane. The fitting results of the close-range metal plate plane are as follows: 1) Total collected data points: 644; 2) Measuring distance: 6m; 3) Exceeding 3 times the number of error elimination points: 1; 4) Fitting error is 0.0016m; 5) The percentage of points exceeding twice the error in the total: 4.7988%.

3.2. Long-distance plane fitting results and analysis

First, use the ground 3D laser scanner to pre-process the collected point cloud data, adjust the angle of view in 3D mode and enlarge the target area, and use the selection mode tool to select the point cloud data of the metal plate with the left mouse button. And then right click to select. Use the Create new poly data object tool to generate a separate area with only the selected part of the selected area under poly data. Next, output the acquired data as a txt file in the form of distance and X, Y, and Z. Use the excel table to sort the distance data, and filter out the point cloud data that meets the requirements through the difference of the measured distance. Input the processed point cloud data into a plane fitting program based on MATLAB design, and get the fitting error of each measurement of the metal plate (see Table 1).

| Numbering | distance | angle  | color | Number of collections | Error in fitting/m |
|-----------|----------|--------|-------|-----------------------|--------------------|
| Polydata001 | 300      | vertical | Glossy | 504                  | 0.0079             |
| Polydata002 | 300      | vertical | color  | 185                  | 0.0071             |
| Polydata003 | 300      | tilt     | Glossy | 181                  | 0.0052             |
| Polydata004 | 300      | tilt     | color  | 130                  | 0.0066             |
| Polydata005 | 160      | vertical | Glossy | 436                  | 0.0020             |
| Polydata006 | 160      | vertical | color  | 1241                 | 0.0030             |
| Polydata007 | 160      | tilt     | Glossy | 1101                 | 0.0029             |
| Polydata008 | 160      | tilt     | color  | 1001                 | 0.0027             |
| Polydata009 | 110      | vertical | Glossy | 527                  | 0.0019             |
| Polydata010 | 110      | vertical | color  | 536                  | 0.0016             |
| Polydata011 | 110      | tilt     | Glossy | 428                  | 0.0037             |
| Polydata012 | 110      | tilt     | color  | 362                  | 0.0019             |
| Polydata013 | 60       | vertical | Glossy | 200                  | 0.0015             |
| Polydata014 | 60       | vertical | color  | 196                  | 0.0013             |
| Polydata015 | 60       | tilt     | Glossy | 178                  | 0.0023             |
Comparing the uncorrected measurement result of the ground 3D laser scanner with the real value, it can be seen from Fig. 2 that at a distance of less than 50 m, the distance measurement accuracy with a spherical target is at least 8.5 mm, which is lower than the nominal 4 mm/50 m accuracy.

Due to the particularity of the 100 m inspection and calibration site, there are points distributed at the distances of 10 m, 20 m, 40 m, 60 m, 80 m, and 100 m. Therefore, the uncorrected measurement results of the ground 3D laser scanner are compared with the real values. Compare. It can be seen from Figure 3 that within the range of 100 m, the range accuracy of the spherical target is within 40 m, the minimum accuracy is 3.6 mm, and the accuracy is at 60 m, 80 m, and 100 m. They are 4.8 mm, 6.3 mm, and 7.7 mm respectively [6].

Figure 2. Error of initial laser scanner ranging value.

Figure 3. Test error.
The nominal angle measurement accuracy of the 3D laser scanner is 0.007°, 20m and 40 m warp beam error correction, the error of the angle measurement is 0 respectively. 0.001 469°, and both are smaller than the nominal error, so the horizontal angle measured at 20 m and 40 m meets the factory's nominal accuracy of the scanner. The method of controlling variables is used to study the accuracy of the three-dimensional laser scanner measuring horizontal angle at different distances (20 m, 40 m). The test results show that the accuracy of the Z + FIMAGER 5010C three-dimensional laser scanner is slightly different at different distances, but All comply with the nominal accuracy [7].

4. Conclusion

Ground-based 3D laser scanners are mainly used for 3D modeling and virtual reality, and to generate measurable images based on point clouds. As a high-tech for obtaining three-dimensional spatial information, the performance of its instrument determines the quality of the measurement results, and its measurement accuracy directly determines its application field and application range, so it is very important to evaluate its measurement performance. Taking this as an example, this paper evaluates its performance from the accuracy of range measurement, angle measurement and point location accuracy. In addition, the registration accuracy of the point cloud and the modeling accuracy of the point cloud will be the next research work. The main conclusions of this paper are: 1) The accuracy of terrestrial 3D laser scanners is evaluated by a high-precision, long-running baseline verification field. The method is simple to operate, time-saving, labour-saving, high-precision and traceable. 2) The multi-tooth indexing table can be used for the horizontal angle accuracy evaluation of the ground 3D laser scanner. This method does not require multiple target points, and has high accuracy, good stability and traceability. 3) The indoor inspection and calibration field can be used to evaluate the point position accuracy through multiple targets with known coordinates. 4) The machine's ranging accuracy is 1 to 2 mm, which meets the nominal accuracy; the angle measurement accuracy is about 15″; the point position accuracy can reach the millimetre level, which is greatly affected by the distance.

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