2018 International Conference on Chemical, Physical and Biological (ICCPB2018)

Research on Point Cloud Data Registration Method Based on Ground 3D Laser Scanning

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Abstract—**At present, the continuous advancement of science and technology, the requirements for digitization in various fields are getting higher and higher. As a tool for 3D point cloud acquisition, 3D laser scanners are increasingly researched and developed, and scanners with different performances are used in different fields. The registration of point cloud data by these workers is the key to the success of the project. The point cloud data of all the different coordinate systems are all registered, so that the complete point cloud data of the measured entity can be obtained, and the entity with the measured entity is Complete point cloud data is ready for the next step. This paper studies the registration method of point cloud data, discusses the commonly used registration methods in detail and then analyzes the point cloud error, and then derives the propagation model of point cloud error. Finally, design a set of schemes to complete the building. Scanning data is obtained by scanning, and the data is registered by target and non-target respectively; the differences in the registration process are compared, and the results are analyzed and compared.**

Keywords—3D laser scanning, point cloud data, registration, error propagation

I. Introduction

The essence of point cloud data registration is to convert the coordinates in two coordinate systems into a unified coordinate system.[1-2] In order to achieve this process, the same part between the two coordinate systems must be found, that is, in two Find the same position in the adjacent scanned 3D view, that is, the common point, and use the same part between the two to achieve the unification of the coordinates. The method of point cloud registration is generally divided into feature registration and featureless registration.[3-4] This classification is based on the primitives on which the registration process is based.

II. Point cloud registration method

A. Feature Registration

Feature registration is to use the feature points for registration. In the views obtained from the two adjacent scans, find some points that are easy to identify, easy to mark, and common to both.[5-8] Through these points, the conversion of two coordinate systems to one coordinate system is completed. According to these different feature points, the feature registration is divided into target registration and targetless registration.

Target registration is the use of targets for point cloud registration. The target is placed in the scanning field of view of the scanner before data collection. There are generally two groups, and the number of targets in one group is three or more. The point cloud data scanned by this method contains the point cloud data of the target.[9-10] When the point cloud registration is performed, the target scan data does not need to be specifically used to find the feature point, and only needs to automatically or manually extract the target. Then, point cloud registration can be achieved by using common targets between adjacent point clouds. Target registration is a kind of registration method with high precision, high registration efficiency and simple operation in feature registration, which is widely used in work.

Target-free registration is done by not using the target but by using other feature points of the measured entity. When performing registration, first observe the characteristics of the measured entity's appearance, manually select the feature points according to the specific characteristics, and select the remaining steps after the feature points are the same as the target registration, find the common points between adjacent point clouds for registration.

B. Featureless Registration

Feature points are not required for feature registration. If it is decided to perform featureless registration on the point cloud data, there is no need to place the target when scanning the spatial entity, and there is no need to specifically mark the feature point during the registration process, and feature points are not needed in the entire registration process. The basic principle of featureless registration is performed by the ICP algorithm, which is also called the iterative closest point algorithm. The principle of the ICP algorithm is to treat two adjacent parts of the point cloud data with the common part as the set of two points H and L, and then use some methods to calculate R and T, and R represents the rotation transformation between the two coordinate systems. , T represents the coordinate translation transformation between the two coordinate systems. Next, R and T are initialized, and the iterative operation is started after initialization, that is, the iterative operation is used to find the point in the set H through R, the nearest point in the L after the T transform, and the next match is found, so that all the loops are found. The closest point is to complete the registration of point cloud data.

III. Point cloud error propagation model derivation process

According to the principle of point cloud registration, solving six spatial similarity transformation parameters is a key part of point cloud registration. Generally, three or more pairs of the same name are used, and then solved by least squares adjustment method. The error existing in the quasi-middle introduces the following point cloud registration error propagation

  DOI: 10.25236/iccpb.2018.006

model:

$$F=\begin{pmatrix}X\\Y\\Z\end{pmatrix}=R(\varphi,\omega,\kappa)\begin{pmatrix}x\\y\\z\end{pmatrix}+\begin{pmatrix}\Delta X\\\Delta Y\\\Delta Z\end{pmatrix} \quad (1)$$

In the formula (1), (X, Y, Z) and (x, y, z) represent the coordinate values of two points of the same position in different coordinate systems, and R is a rotation matrix, and the formula is given by the Taylor series (1) Expand and then take the number of items once, the error equation that can be obtained is:

$$V^k=\left(\frac{\partial F}{\partial\Delta X}\right)d\Delta X+\left(\frac{\partial F}{\partial\Delta Y}\right)d\Delta Y+\left(\frac{\partial F}{\partial\Delta Z}\right)d\Delta Z+\left(\frac{\partial F}{\partial\Phi}\right)d\Phi+\left(\frac{\partial F}{\partial\Omega}\right)d\Omega\ +\left(\frac{\partial F}{\partial\mathrm{K}}\right)d\mathrm{K}+\left(\frac{\partial F}{\partial x}\right)dx+\left(\frac{\partial F}{\partial y}\right)dy+\left(\frac{\partial F}{\partial z}\right)dz-\left(F-F^0\right) \quad (2)$$

In equation (2), F^0 is a constant term, and let K in equation (2) be the coefficient matrix of V^κ, which gives:

$$K=\begin{bmatrix}\frac{\partial fx}{\partial X}&\frac{\partial fx}{\partial Y}&\frac{\partial fx}{\partial Z}&\frac{\partial fx}{\partial\varphi}&\frac{\partial fx}{\partial\omega}&\frac{\partial fx}{\partial\kappa}&\frac{\partial fx}{\partial x}&\frac{\partial fx}{\partial y}&\frac{\partial fx}{\partial z}\\\frac{\partial fy}{\partial X}&\frac{\partial fy}{\partial Y}&\frac{\partial fy}{\partial Z}&\frac{\partial fy}{\partial\varphi}&\frac{\partial fy}{\partial\omega}&\frac{\partial fy}{\partial\kappa}&\frac{\partial fy}{\partial x}&\frac{\partial fy}{\partial y}&\frac{\partial fy}{\partial z}\\\frac{\partial fz}{\partial X}&\frac{\partial fz}{\partial Y}&\frac{\partial fz}{\partial Z}&\frac{\partial fz}{\partial\varphi}&\frac{\partial fz}{\partial\omega}&\frac{\partial fz}{\partial\kappa}&\frac{\partial fz}{\partial x}&\frac{\partial fz}{\partial y}&\frac{\partial fz}{\partial z}\end{bmatrix} \quad (3)$$

Let $X_d=[d\Delta X\quad d\Delta Y\quad d\Delta Z\quad d\Phi\quad d\Omega\quad d\kappa\quad dx\quad dy\quad dz]^T$, formula (2) can be expressed as:

$$V^\kappa=KX_d-L$$

Let the registration variance of the 6 parameters and snacks, x, y, z be:

$$\sigma_\varphi^2\quad\sigma_\omega^2\quad\sigma_\kappa^2\quad\sigma_{\Delta X}^2\quad\sigma_{\Delta Y}^2\quad\sigma_{\Delta Z}^2\quad\sigma_x^2\quad\sigma_y^2\quad\sigma_z^2$$

Let the weight matrix of the 6 parameters be:

$$P,\ D_x=\left[\ \sigma_\varphi^2\quad\sigma_\omega^2\quad\sigma_\kappa^2\quad\sigma_{\Delta X}^2\quad\sigma_{\Delta Y}^2\quad\sigma_{\Delta Z}^2\quad\sigma_x^2\quad\sigma_y^2\quad\sigma_z^2\right]$$

Then the variance of the points x, y, z is:

$$D=\left[\sigma_x^2\quad\sigma_y^2\quad\sigma_z^2\right]$$

Then the variance corresponding to X_d is:

$$D_n=\left[\ \sigma_\varphi^2\quad\sigma_\omega^2\quad\sigma_\kappa^2\quad\sigma_{\Delta X}^2\quad\sigma_{\Delta Y}^2\quad\sigma_{\Delta Z}^2\quad\sigma_x^2\quad\sigma_y^2\quad\sigma_z^2\right]$$

Finally, let P be the identity matrix. According to the principle of indirect adjustment, the solution of the unknown is obtained when V^TPV is the smallest:

$$X=\left(B^TB\right)^{-1}B^TL \quad (4)$$

σ^2 is the unit weight error.

$$\sigma_0^2=\frac{V^TPV}{3n-6} \quad (5)$$

Using the propagation law of the co-factor, the solution formula for the 6-parameter is:

$$D_X = \sigma_0^2 Q_{xx} \quad (6)$$

The cofactor matrix is:

$$Q_{\hat{x}\hat{x}} = Q - BQ_{xx}B^T \quad (7)$$

The variance of the observed value estimates:

$$D = \sigma_0^2 Q_{\hat{x}\hat{x}} = \sigma_0^2 Q - BD_X B^T \quad (8)$$

The 9*9 diagonal square matrix is D_N , let $D_M = \lfloor \sigma_x^2 \ \ \sigma_y^2 \ \ \sigma_z^2 \rfloor$, then get:

$$D_M = KD_N K^T \quad (9)$$

Equation (9) is an error propagation model for point cloud registration in two different coordinate systems. The formula (10) can be used to check out the point error after registration is completed, which is an indicator for judging point registration.

The experiments carried out in this paper are carried out according to the following steps. After the design of the scheme is completed, the point cloud data is collected by the scanner, and then the registration is performed by using the Haida registration software. The two methods, namely the feature point and the target registration, are used for registration. Finally, the data analysis of the registration results.

IV. Design

This data acquisition selects a clock tower as the object. According to the shape characteristics of the clock tower, the scanner is placed in the four directions of Zhengdong, Zhengnan, Zhengxi and Zhengbei respectively. Each scanning station is set up in each direction, for a total of 4 scans. station. This scan needs to set 6 targets, divided into two groups, one set is three, four scans from four directions, to get the complete three-dimensional point cloud data of the clock tower. After obtaining the point cloud data of the tested entity, registration is started using the registration software. The registration uses two methods, one is the target-free label registration method and the other is the target ball registration method.

In the target ball registration, the target placed in this scan is two groups, each set of three target balls, each target ball in each point cloud view is found and marked, and the automatic mark which the software has can be used when marking The target ball function can also be manually marked. In the automatic marking, because the position of the individual target ball in the point cloud is not obvious, the final target ball cannot be found one by one during the automatic scanning. At this time, it is manually marked. The way to find the target, generally using the point cloud registration of the feature points, the target ball is combined with the two methods of automatic marking and manual marking to achieve the marking of all the target balls. After the marking is completed, click the point cloud registration to complete the registration of the two point clouds according to the target ball at the same position in the adjacent view.

In the targetless registration, the point cloud data is imported into the registration software and enters the point cloud interface. Then, the feature points are selected according to the characteristics of the building clock tower. In this registration, two sets of feature points are selected. The group is composed of three feature points. The position of the selected feature points is the bottom point of the clock tower, and the inflection point between the vertices and the pillars. Due to the symmetry of the clock tower of the tested building, the selected points are highly representative, which greatly improves the registration. s efficiency. After the feature point is selected, click Save, and finally register the point cloud data, open the registration interface, find the feature points of the same position between the two adjacent point cloud views, and use the feature points to complete the matching of the point clouds. quasi.

A. Data Collection

The object scanned this time is the clock tower of the school building. The scanning instrument used is Z+F 5010c. According to the design scheme, 6 spherical targets are scanned and scanned 4 times, so that the complete 3D point cloud data of the clock tower of the measured object can be obtained. . First, place the instrument at position 1 of the clock tower and place spherical targets on both sides. After the scan is completed, transfer the instrument to position 2, the position of the adjacent target ball is unchanged, and the other set of target balls are placed on the right side of the instrument to start scanning. Manage the rest of the scan.

B. Point Cloud Registration

After processing the scanned raw data, perform point cloud registration. First, import the data. This point cloud registration is performed in two ways. One is to use the target ball for registration, and the other is to use the feature points for registration.

After the registration is completed, the errors of the two registrations are analyzed, and the two types are compared. The details of the registration method result in a highly accurate registration method.

C. Registration Using Feature Points

When registering point cloud data, use the feature points in the view for registration. Firstly, according to the characteristics of the building itself, the point of the building itself with obvious features is selected as the feature point. Then find the points in the same position in two adjacent views, and finally perform point cloud registration.

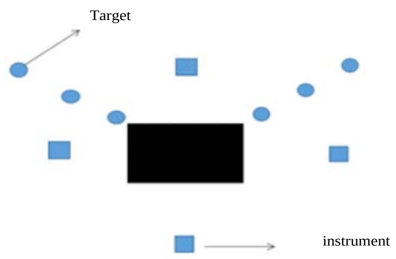

Figure 1. Data acquisition diagram

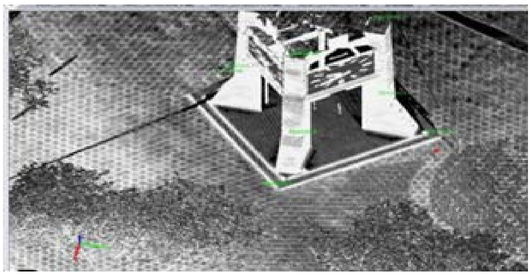

Figure 2. Mark feature point

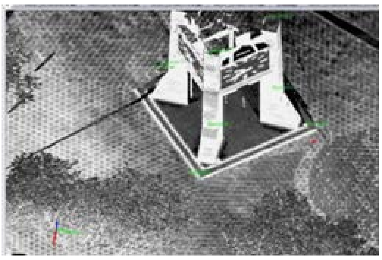

Figure 3. Feature point registration result graph

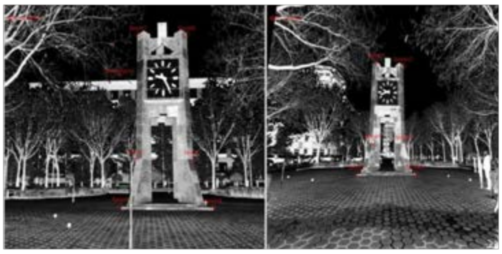

Figure 4. Feature point registration details

D. Registration Using the Target Ball

The principle and process of target ball registration are similar to the registration process of feature points. The difference is that the former uses the target ball placed during scanning to register. First, the registration software is used to scan the view to automatically mark the target ball. However, in the process of auto-marking, individual target balls are not marked. In this case, manual marking is used, that is, the target ball that is not marked is found by observing the view. Manually mark, save after the target ball mark is completed, then find the same position in the two views of the registration, register, and preview the view after completion. After completing the registration of all the target balls at the same position, you can browse to The result graph after registration.

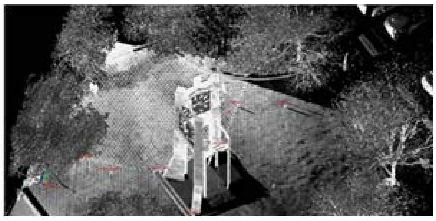

Figure 5. Target registration result

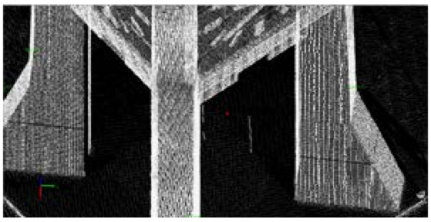

Figure 6. Target registration details

E. Error Analysis

From the comparison of the two methods, the precision relationship between the two is analyzed. In the target registration in the table, the final average error of the data is 0, and there is a certain error in the registration of the feature points, where {delta x y z d} They are the displacement changes of the point cloud in its direction during the registration process.

TABLE 1. FEATURE POINT COORDINATE VALUE

Name	Type	Ref X	Ref Y	Ref Z	Reg X	Reg Y	Reg Z
7	Feature	-6.503	12.817	-1.388	11.423	-6.630	-1.308
8	Feature	-7.945	13.201	0.882	11.223	-8.112	0.985
9	Feature	-8.112	13.218	7.847	11.221	-8.297	8.010
13	Feature	7.935	-10.569	-1.308	11.263	-10.003	-1.553
14	Feature	9.387	-10.771	0.959	10.826	-11.386	0.733
15	Feature	9.530	-10.787	7.963	10.786	-11.532	7.695
17	Feature	7.130	-13.221	-1.556	12.044	-10.324	-1.410
18	Feature	8.521	-13..672	0.732	11.616	-11.747	0.884
19	Feature	8.665	-13.221	7.713	11.594	-11.906	7.937

TABLE 2. CHARACTERISTIC POINT ERROR ANALYSIS

Name	Type	Delta X	Delta Y	Delta Z	Delta D	average error
7	Feature	36	4	0	36	
8	Feature	12	3	0	12	36
9	Feature	49	7	1	48	
13	Feature	7	6	0	1	
14	Feature	21	8	1	20	18
15	Feature	22	1	0	22	
17	Feature	51	3	1	51	
18	Feature	22	7	2	21	37
19	Feature	31	10	3	29	

TABLE 3. TARGET SPHERICAL COORDINATE VALUE

Name	Type	Ref X	Ref Y	Ref Z	Reg X	Reg Y	Reg Z
7	Target	-2.307	9.453	-1.437	14.312	-2.053	-1.361
8	Target	-2.906	12.569	-1.423	11.287	-3.012	-1.346
9	Target	-6.984	12.863	-1.184	11.470	-7.096	-1.106
15	Target	8.433	-10.567	-1.107	11.209	-10.478	-1.357
16	Target	5.270	-11.531	-1.335	10.825	-7.194	-1.582
17	Target	3.397	-10.883	-1.340	11.798	-5.467	-1.588
19	Target	3.057	-12.140	-1.582	13.035	-6.226	-1.426
20	Target	5.016	-14.030	-1.578	11.209	-8.245	-1.422
21	Target	7.588	-13.279	-1.355	12.040	-10.79	-1.799

TABLE 4. TARGET BALL ERROR ANALYSIS

Name	Type	Delta X	Delta Y	Delta Z	Delta D	average error
7	Target	0	0	0	0	
8	Target	0	0	0	0	0
9	Target	0	0	0	0	
13	Target	0	0	0	0	
14	Target	0	0	0	0	0
15	Target	0	0	0	0	
17	Target	0	0	0	0	
18	Target	0	0	0	0	0
19	Target	0	0	0	0	

F. Registration Result

After each part of the point cloud registration is completed, preview the view, check the effect of the two point cloud registration and save it in time to avoid data loss, select different reference coordinate systems to complete the point cloud registration between different parts, and then click on the 3D view. Browse the 3D view so that you get the 3D point cloud data of the complete measured entity. The registration of each part of the point cloud is completed, which means that the point cloud data has been unified into one coordinate system, and the integration between different coordinate systems is realized, which indicates the completion of the point cloud registration.

V. CONCLUSION

In this point cloud registration, two different methods are used to register the point cloud data, and the same parts and differences between the two are compared. The comparison contents are as follows: the accuracy of the registration of the two methods is compared and compared, and the details of the registration results between the two are compared, and the registration process between the two is introduced. According to the comparison, the result of using the feature point registration is lower in precision and larger in error. The process of finding feature points is cumbersome and inefficient. Although the registration can be completed, the error is large, and the obtained point cloud data has low precision, which is not conducive to The next step of the 3D model reconstruction process; the accuracy of the target ball registration is high, the error is small, the process of marking the target ball is relatively simple and fast, the efficiency is high, the obtained point cloud data has high precision, and the use of 3D modeling is utilized. The operation of cloud data can play a better role.

ACKNOWLEDGEMENT

School youth fund of Lanzhou Jiaotong University, Application of dynamic inversion in deformation early warning of deep foundation pit, No. 2017001

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