Ancient Architecture Reconstructing Based on Terrestrial 3D Laser Scanning Technology

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***Abstract*—Ancient architecture protection and reconstruction is very important application of Terrestrial 3D Laser Scanning technology (TLS).The paper, after discussing working principle and workflow of TLS and point cloud registration based unit quaternion, analyzed and researched of the algorithm and principle and steps of spherical projection based triangulation, tried to give an effective method and process of ancient architecture protection and reconstruction. The case of the ancient architecture verified its feasibility. It is of great significance to research data processing and 3D Modeling.**

Keywords-TLS; Ancient architecture; Spherical projection; 3D Reconstructing

I. INTRODUCTION

In Civil Engineering, Industrial Design, Ground Models, Road and Bridge Design, Ship Building, Geographic Data Collection, On-site Protection, Opencast Coal Mine Mining, Construction Monitoring and many other areas, terrestrial 3D laser scanning technology has been successful applications. Its high efficiency and low cost obtained wide recognition. Archeology and cultural heritage, in particular the protection of ancient buildings, are one of the earliest TLS applications.

TLS can fast digitize the archaeological sites and cultural sites for true record of the status quo of pre-and-post archaeological excavations of the sites and cultural heritage, providing vivid and detailed information of structure and component parts, representing three-dimensional model of artifacts and cultural sites. This provides the required information of historic reconstruction or transformation, and can draw out the necessary site plans as a basis for monitoring and evaluation. However, at field surveying, the efficiency and adequacy of TLS field surveying data collection cannot hide the difficulty of its indoor data processing. Point cloud data processing technology and related software have not reached the mature stage, still in the chaotic phase, to be systematized and theorized. Moreover, there are too many three-dimensional modeling method based point cloud data without a universal standard.

On the basis of TLS, the paper gave a process and method of ancient architecture three-dimensional reconstruction and case verification. It achieved the purpose of the ancient architecture protection and verified that the method is feasible and efficient, but also promoted the development of TLS technology. There is great significance in the research of point cloud data three-dimensional modeling method.

II. TLS PRINCIPLE

Currently on the market, TLS are generally based pulse. The raw observational data of TLS includes the three-dimensional coordinates of scan points, reflection intensity, color information, which can be used for point cloud data post-processing and provides a physical edge location information and color texture information. Fig.1 is a schematic diagram of TLS scanning.

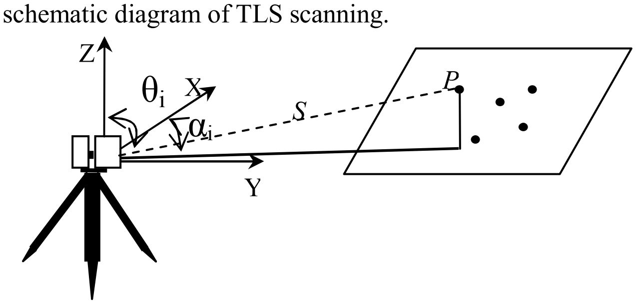


Figure 1.TLS scanning schematic diagram

TLS system generally applies the coordinate system of the instrument interior: X-axis in the horizontal scanning plane; Y-axis in the horizontal scanning plane and is vertical with the X-axis; Z axis is vertical with the horizontal scanning plane, which constitutes a right-handed coordinate system. According to Fig.1, the scanning point coordinate can be calculated by following formula [1]:

$$x = s\cos\varphi\cos\theta,\quad y = s\sin\varphi\cos\theta,\quad z = s\sin\theta \qquad (1)$$

TLS scanning data output is called point cloud data. Through software processing, points, lines, polygons, surface and other factors can be extracted from point cloud data, which can be used for rebuilding the physical surface model. Software processing results can be converted into other formats which can be applied to other engineering.

III. TLS OPERATION PROCESS

TLS surveying steps generally include the preparation of pre-scan, field scanning, point cloud data processing and 3D modeling etc., and the workflow shown in Fig.2, in which point cloud data processing can be divided into three steps: point cloud data acquisition, point cloud data processing and the establishment of space three-dimensional model. According to research topics of data processing, it can be further subdivided as follows: point cloud data acquisition, registration, analysis, surface fitting and data partitioning, reduction, the establishment of spatial three-dimensional models, texture mapping and so on.

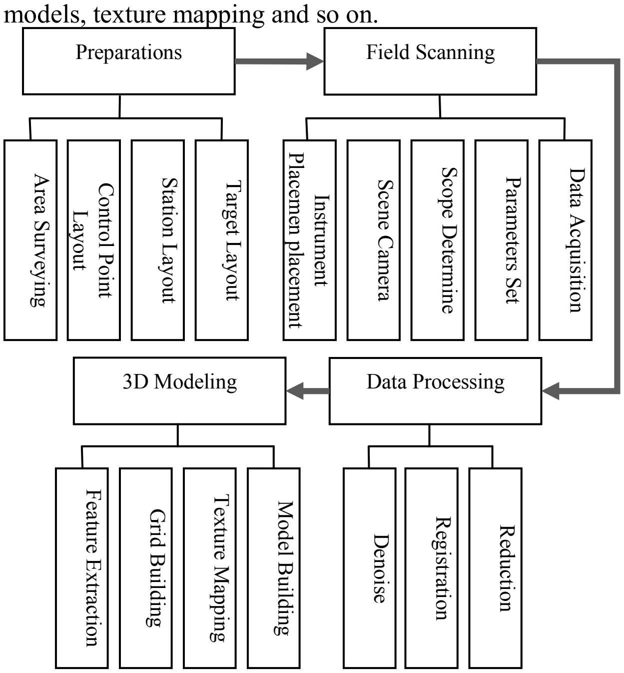


Figure 2.TLS scanning workflow

IV. REGISTRATION OF POINT CLOUD DATA

Given the limitations of scanning view and the need for practical application of TLS system, in order to obtain complete information of the physical surface, TLS needs to scan the entity surface from different locations. Point cloud data registration is one of TLS core technology, one aim of which is to transform different coordinates of the point cloud coordinates into a unified coordinate system [3]. Registration technique has wider and wider applications in Quality Control, Face Recognition, Fingerprint Recognition, Image Matching, as well as Archeology.

A. The principle of point cloud registration

Registration is only related to rotation and translation of the rigid transformation. A set of point cloud data rigid transformation can be expressed as rotation matrix R and translation matrix T, which makes the point cloud only transform the location and distance. In the three-dimensional space, the rotation matrix R and translation matrix T can be expressed as:

$$R=\begin{bmatrix}\cos\alpha & -\sin\alpha & 0\\ \sin\alpha & \cos\alpha & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}\cos\beta & 0 & \sin\beta\\ 0 & 1 & 0\\ -\sin\beta & 0 & \cos\beta\end{bmatrix}\begin{bmatrix}1 & 0 & 0\\ 0 & \cos\gamma & -\sin\gamma\\ 0 & \sin\gamma & \cos\gamma\end{bmatrix} \quad (2)$$

$$T=\begin{bmatrix}t_x & t_y & t_z\end{bmatrix}^T$$

Where α, β, γ express rotation angle along X,Y,Z axis, t_x, t_y, t_z express the amount of displacement.

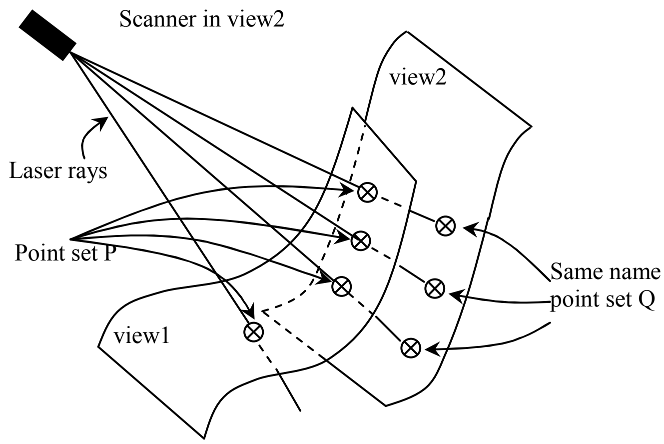


Figure 3.Point cloud registration principle

For the two space point cloud sets to be matched: P = {p_i}, Q = {q_i}, i = 1, 2, …, N (Fig.3.), the goal is to find the optimal rotation matrix R and translation matrix T , so that the value of the following function can achieve the minimum:

$$f(R,T)=\sum_{i=1}^{N}\| p_i-(Rq_i+T)\|^2 \quad (3)$$

The function f (R, T) shall be the objective function. The objective function in fact reflects the transformation difference between the two point clouds with various selection methods. According to the different methods, algorithms results and efficiency are also different.

B. Point cloud registration Based on the unit quaternion

From the above we can see that the key to transformation parameters is to calculate the rotation matrix. There are many in rotation matrix representation, such as Euler angles, Cayley-Klein parameters, axis and rotation, Unit quaternion, etc. Using different rotation matrix representation, mathematical model solution is different. Mathematician Hamilton in 1843 created the quaternion, which is a column vector contains four elements, its representation as [4], [6]:

$$\mathbf{q}=w+x\mathbf{i}+y\mathbf{j}+z\mathbf{k} \quad (4)$$

Where w is a scalar, (x,y,z) is a vector. To facilitate that, the quaternion q is expressed as (w, V), where w is the quaternion scalar part, V, said part of the quaternion vector (x,y,z) . Therefore, a three-dimensional vector $\mathbf{p}=(p_1 \quad p_2 \quad p_3)^T$ can be expressed as $\mathbf{P}=0+p_1\mathbf{i}+p_2\mathbf{j}+p_3\mathbf{k}=(0,\mathbf{p})$; and a scalar a can be expressed as $\mathbf{a} = a + 0\mathbf{i} + 0\mathbf{j} + 0\mathbf{k} = (a, \mathbf{0})$. Quaternion multiplication can be the form of a matrix. According to the characteristics of orthogonal matrix, based on quaternion multiplication, we can obtain 3 * 3 matrix of q based on the unit quaternion, namely, three-dimensional rotation matrix:

$$\mathbf{R} = \begin{bmatrix} 1-2(y^2+z^2) & 2(xy-wz) & 2(wy+xz) \\ 2(xy+wz) & 1-2(x^2+z^2) & 2(yz-wx) \\ 2(xz-wy) & 2(yz+wx) & 1-2(x^2+y^2) \end{bmatrix} \quad (5)$$

According to the nature of computing orthogonal matrix, R must be orthogonal matrices, and $|\mathbf{R}| = 1$. According to the relationship of direction cosine and angular elements in rotating matrix, we can also calculate various angle of rotation [6]:

$$\tan\varphi = -\frac{a_3}{c_3}, \sin\omega = -b_3, \tan k = \frac{b_1}{b_2} \quad (6)$$

Through the above derivation, we can see that the unit quaternion-based calculation model does not need linearization, the initial value of the rotation and the limitation of the size of the angle, simplifying the calculation. Its shortcoming is that theoretical precision assessment has a certain difficulty. For its efficient and accurate enough to meet the registration requirements, this paper implements the ancient buildings point cloud registration by it.

V. THREE-DIMENSIONAL MODELING OF ANCIENT ARCHITECTURE

At present, there are very many modeling methods based on point cloud, but more sophisticated and efficient algorithm has not been formed. This article makes the three-dimensional model on point cloud data based on spherical projection grid method [4], [7], and an ancient buildings point cloud modeling tested and verified the method is feasible.

A. The principle of regular grid method based on spherical projection

Spherical projection regular grid algorithm is that point by point insertion method of two-dimensional Delaunay triangulation to build grid extended to the ball surface [4]. Its algorithm is as follows:

1) Defining projection sphere, with the way of center projection the data points projected onto the spherical surface.

2) Establishment of initial spherical Delaunay triangulation.

3) According to spherical Delaunay criteria, The points projected onto the sphere insert into triangular mesh, and the process will continue until all points have inserted into the mesh.

4) Removing the initial triangulation vertices, and partially repairing triangular network.

5) Holding triangular relationship of projection point on the sphere, the projection points are anti-projected onto its original location, and to complete the triangular network.

Based on the above ideas, Fig.4 is the spherical projection method flow chart, its algorithm is clear and concise, and easy to implement multi-detail and multi-resolution model, which is to facilitate post-compression processing.

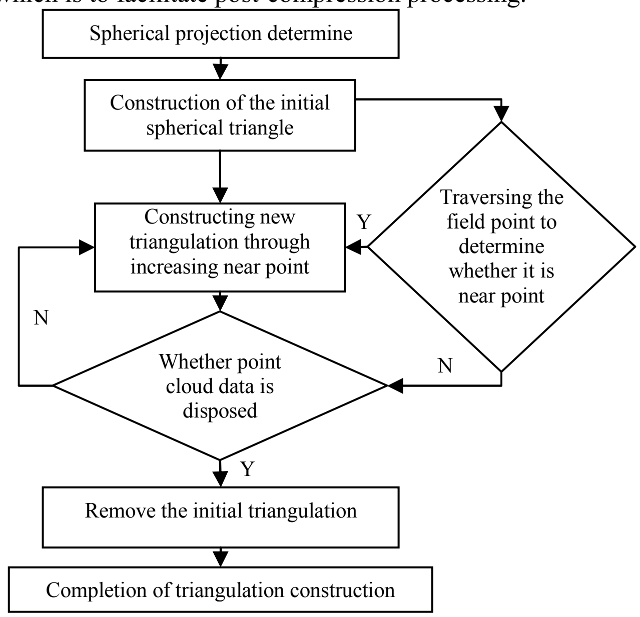


Figure 4.Grid construction flow chart based on spherical projection

B. Ancient architecture three-dimensional modeling realization based on TLS

1) Surveying method

Through laying targets within the overlapping region, some ancient architecture was scanned in different scanning stations, and then to extract the target coordinates in the adjacent two scanning station. Under the coordinates transform formula (2), the rotation, pan transformation parameters between adjacent two scans were calculated, by which the point cloud data of various scans could be transformed into the same coordinate system according to formula (7):

$$\begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} = R(\alpha_1, \alpha_2, \alpha_3) \begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix} + \begin{pmatrix} \Delta x \\ \Delta y \\ \Delta z \end{pmatrix} \quad (7)$$

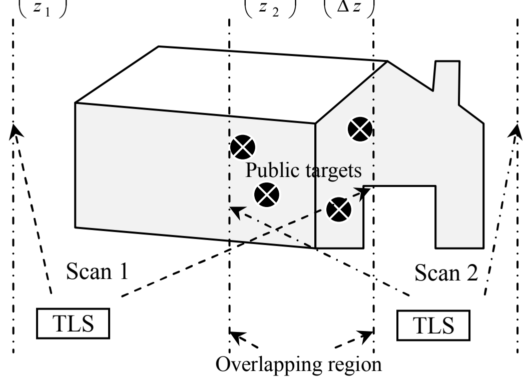


Figure 5.Surveying program based on TLS

Where (x_1, y_1, z_1) and (x_2, y_2, z_2) is the each coordinates of two adjacent scan coordinate system. Fig.5 showed surveying program based laying targets within the overlapping region of two adjacent scan stations.Fig.6 is scan data of the 5 stations.

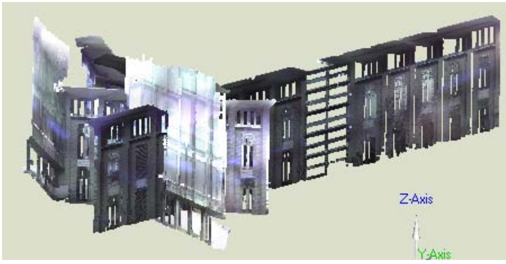


Figure 6.Scanning data of 5 stations

2) Data processing

The center coordinates of the target were extracted by home-made software or commercial software. By the unit quaternion-based point cloud registration method transformation parameters were obtained. The results shown in Table 1:

TABLE I. REGISTRATION RESULTS OF 5 STATIONS UNIT:METER

First station	Rotation matrix	Translation parameters
	0.9992 -0.0404 0.0006 -0.0404 -0.9992 -0.0022 -0.0007 -0.0022 1.0000	16.0362 5.3254 11.6895
Second station	Rotation matrix	Translation parameters
	-0.4211 -0.9070 -0.0030 -0.9070 0.4211 -0.0001 -0.0013 -0.0027 1.0000	-25.8064 38.3494 11.532
Third station	Rotation matrix	Translation parameters
	0.4206 0.9072 0.0030 0.9072 -0.4206 -0.0003 -0.0010 -0.0028 1.0000	36.2102 21.511 11.449
Fourth station	Rotation matrix	Translation parameters
	0.3557 -0.9346 -0.0020 -0.9346 -0.3557 -0.0019 -0.0011 -0.0026 1.0000	-16.7523 15.8079 11.816
Fifth station	Rotation matrix	Translation parameters
	-0.8215 -0.5702 -0.0026 -0.5702 0.8215 0.0020 -0.0010 -0.0031 1.0000	10.2278 43.4880 11.499

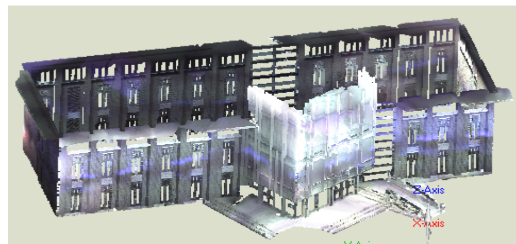
3) Three dimensional modeling

According to the principle of Spherical projection regular gird method and Fig.4, the paper implemented this algorithm using VC + +. NET and Open Inventor. Fig. 7 shows the point cloud data processing results. The top of Fig. 7 is the single-site cloud modeling diagram and the next is the overall three-dimensional modeling diagram after registration.

VI. CONCLUSION

Based three-dimensional scanning technology, this paper explored and studied the instrument operational principles, procedures and methods; unit quaternion-based point cloud registration method and operational programs based target; analyzes three-dimensional model establishment based on spherical projection regular grid method, and therefore effectively established a three-dimensional model of some ancient buildings. Model establishment further validated the correctness and efficient of algorithms and methods which was of great significance to research of point cloud data processing technology, and could be replicated in other engineering applications. However, this model building process also encountered some difficulties: Due to the phenomenon of severe occlusion, occlusion forms complex, it is very difficult to remove noise and mend leakage; When spherical projection overlapping, the part model data can be lost; For the sake of expectation resolution limitations, the boundary was not clear. These will be the next step of this article which needs to be studied and solved.

Single-site modeling



Overall modeling

Figure 7.Ancient architecture 3D model based on spherical projection regular grid method.

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