Research and Analysis of Ancient Architectural Elements Based on 3d Basic Model

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Abstract: Ancient buildings have undergone hundreds of years of changes and vicissitudes, in an extremely fragile situation, ancient building protection and repair work cannot be delayed, the task of digital archiving and protection of ancient buildings is urgent. Traditional archival protection of ancient buildings relies on manual point measurement, written records, shooting images or video, etc., which is more difficult to obtain the complete spatial three-dimensional and cultural and damage information of ancient buildings, and low efficiency, long cycle, and easy to cause secondary damage to ancient buildings. Therefore, this paper combines the ground 3D laser, airborne LiDAR scanning and unmanned aerial tilt photogrammetry three kinds of real 3D technology to carry out comprehensive ancient building real 3D data acquisition and processing, ancient building 3D model data fusion and ancient building cultural information and damage information extraction method research, realize the ancient building 3D model data fusion based on improved feature point matching algorithm, based on K-Means and IsoData clustering algorithm based on the extraction of cultural information of ancient buildings, based on digital image processing technology of ancient building wall crack damage information extraction and GIS analysis technology based on the analysis of ancient building ground water and volume calculation of the water area.

Keywords: Digital archiving of ancient buildings; Data Fusion; Cultural Information Extraction; Damage information extraction

1 INTRODUCTION

Chinese ancient architecture has been described as "the history book standing on the Chinese earth", and is the crystallization of Chinese architectural civilization, with a long history and cultural value. It has recorded and witnessed the historical and social changes of China and the tortuous economic, political, and cultural development of the country and the nation[1]. It has not only high architectural, cultural, and artistic values, but also profound historical, scientific, and social values, and is of great significance for conservation. But with the rapid development of China's economic and social as well as modernization, ancient buildings and their surrounding environment and landscape protection are facing unprecedented challenges, especially urbanization, new rural areas, the rapid development of tourism, large number of ancient buildings are facing destruction, or even demolition of the tragic situation [2].

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2 GROUND 3D MODEL ALIGNMENT WITH AIRBORNE LIDAR POINT CLOUD MODEL

In order to obtain the complete point cloud model data of the interior and exterior of ancient buildings, this paper uses the 3D point cloud model data of the interior and exterior facades of ancient buildings obtained by ground-based 3D laser scanning and the point cloud model of the roof and its surrounding area obtained by airborne LiDAR for alignment and fusion [3].

The ground 3D laser point cloud and airborne LiDAR point cloud data alignment method is the same as the ground 3D laser different measurement site cloud data alignment method, which is actual kind of rigid body transformation. Firstly, we need to find out the relative position relationship of two points cloud model data and match the two coordinates together by the coordinate mapping relationship between the two data with a certain coordinate as the reference[4]. The airborne LiDAR scans the target M from the air to obtain the point cloud model of the target roof and its building surroundings, and the ground-based 3D laser scans the target M from the ground stand to obtain the 3D point cloud model data of the target interior and exterior facade, where part of the building facade and the building exterior ground are the common scanning area for both data. The point P coordinate system of the airborne LiDAR point cloud model $(x1, y1, z1)$ and the point Q of the ground 3D laser point cloud model $(x2, y2, z2)$ are selected in the common scanning area of the two data, and the coordinate systems of the two point cloud models are converted to the same coordinate system with the airborne LiDAR point cloud or the ground 3D laser point cloud model as the reference, the task of aligning and fusing the indoor and outdoor point cloud models of ancient buildings can be completed [5].

3 Point cloud model and tilt model data fusion

This paper proposes a method to fuse ground 3D laser point cloud model with UAV tilt model data to obtain all-round realistic 3D model data of ancient buildings.

3.1 Model Coordinate Alignment

The current method for fusing the point cloud model with the tilt model is to convert the point cloud model from the scanner's custom relative coordinate system to the absolute coordinate system of the tilt model, mainly using RTK to collect the image control points, the phase control points are selected to be visible in the laser scanning area, and the coordinate information can be collected by selecting the surrounding feature points or the road spray paint to take the central of the method [6]. Then the coordinates are established in the 3D model post-processing software, and a unified coordinate system is established by selecting the marked phase control point and inputting the known coordinates of the point to correspond with the coordinates of the tilt model one by one, the main method of which is realized by the conversion matrix, and the coordinate matching schematic is shown in Figure 1. Although the model coordinate alignment method can align and fuse the tilt model with the point cloud model, there is no difference in this method to align all the point data in common, that is, it cannot eliminate the error larger feature points, thus leading to a larger error in the fusion model [7].

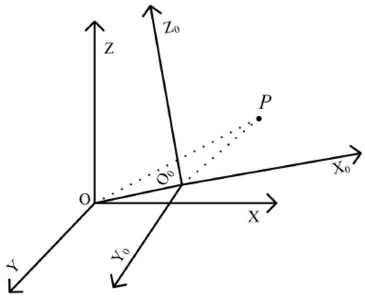


Figure 1: Coordinate matching schematic.

3.2 Improved feature point alignment algorithm

In this paper, the Kd-Tree nearest neighbour search algorithm is used to calculate the normal vector of the fitted plane, to constrain whether the selected homonymous feature points are feasible, as to eliminate the unavailable homonymous points, to optimize the homonymous points, to make the calculated transformation matrix more accurate, and to make the alignment more accurate, and the main process is shown in Figure 2.

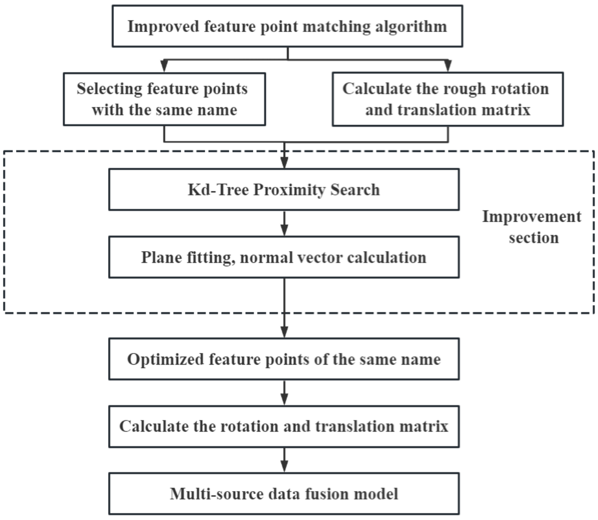


Figure 2: Flow chart of improved feature point matching algorithm.

1) Firstly, we extract the eponymous feature point pairs by hand, and calculate and solve the rotation matrix R1 and translation matrix T1 for both data. The data is roughly spliced;

2) For the coarse spliced data, use the Kd-Tree nearest neighbour search algorithm to first obtain M data points with the closest distance to point $T(x, y, z)$, use these M point cloud coordinates to establish the least squares surface of point T, and calculate the normal vector of the least squares surface $\overrightarrow{a_1}$;

3) Also use the Kd-Tree nearest neighbor search method to obtain $M/2$ data points nearest to point $T(x,y,z)$ from each of the two data, construct the least-squares surface of point T, and calculate the normal vector of the least-squares surface $\overrightarrow{a_2}$;

4) Calculate the normal vectors separately $\overrightarrow{a_1}$、$\overrightarrow{a_2}$ of the angle with the zenith direction a_1、a_2, and calculate a_1、a_2 When the difference is less than or equal to the threshold value, the average value of the coordinates of M points is calculated, and the rotation matrix R and translation matrix T are calculated to fine stitch the two data; when the difference value is greater than the angle threshold, the eponymous feature point is removed and the transformation matrix calculation is recalculated, cycling until all eponymous feature points meet the requirements and then fine splicing is performed, thus continuously improving the alignment accuracy.

The most important feature point matching algorithm is to solve the rotation matrix and translation matrix, and its solution steps are as follows: In the process of two kinds of data fusion, let the original coordinates of laser point cloud data are A and the coordinates of tilt photogrammetry data are B. According to the coordinate values of the same name point location in A and B, the rotation matrix R and translation matrix T can be found by equation (1).

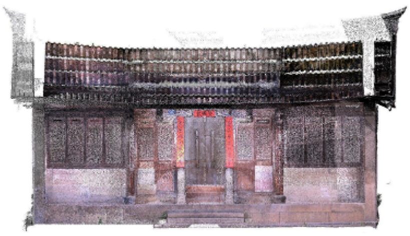
$$P_A = RP_B + T \tag{1}$$

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = R \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} + \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \tag{2}$$

Where PA denotes the coordinate value of the same name point in laser point cloud model A, and PB denotes the coordinate value of the same name point in tilt photogrammetry model B. R is the rotation transformation matrix between the two models. Secondly, the six parameters required for the coordinate transformation of the two data alignments can be obtained by least squares method from the 3D spatial coordinates of three sets of eponymous feature points in laser point cloud model A and tilt photogrammetry model B $(\alpha,\beta,\gamma,t_1,t_2,t_3)$, That is, the values of the rotation matrix R and translation matrix T are obtained, and the final conversion transformation matrix$Q = [R|T]$.

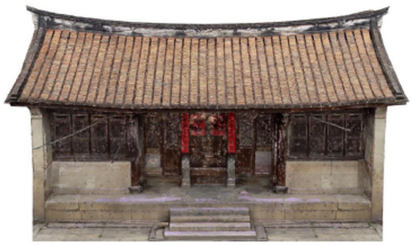
Based on the values of the obtained transformation matrix, the coordinates of the points in the tilt photography model B (X_{Bi},Y_{Bi},Z_{Bi}) The coordinates of the data in the tilt model B in the laser point cloud model A can be obtained by substituting into the conversion equation (4) between the two sites, respectively(X_{Ai},Y_{Ai},Z_{Ai}) That is, the data alignment fusion from tilt photography model B to point cloud model A is completed.

$$\begin{bmatrix} X_{Ai} \\ Y_{Ai} \\ Z_{Ai} \end{bmatrix} = R \begin{bmatrix} X_{Bi} \\ Y_{Bi} \\ Z_{Bi} \end{bmatrix} + \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = Q \begin{bmatrix} X_{Bi} \\ Y_{Bi} \\ Z_{Bi} \end{bmatrix} \tag{3}$$



(a) Point cloud data before fusion

(b) Tilt photography data before fusion



(c) After multi-source data fusion

Figure 3: Comparison before and after multi-source data fusion

After fusion by the algorithm calculation of this study, the laser point cloud data model in the building roof missing data, as well as the tilt photography data model in the phenomenon of pulling and broken holes have been improved to obtain a complete model of ancient buildings, before and after the multi-source data fusion comparison is shown in Figure 3.

3.3 Model accuracy verification

In this study, the point error is used to compare the accuracy of the model data before and after fusion. Due to the high accuracy of the point cloud model, the point-to-point error is 1mm and the alignment error $\leq 2mm$ is closer to the actual size of the ancient building, so the point coordinates of the point cloud model of the ancient building are used as the benchmark (Xu,2021). Twelve corresponding feature points in the point cloud model of ancient buildings and the fusion model are uniformly selected for comparative analysis of model point errors, and the distribution of feature points is shown in Figure 4.

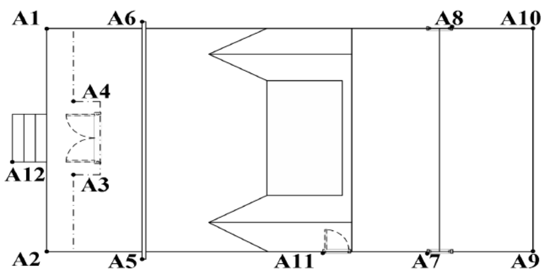


Figure 4: Building feature points

The specific points are as follows: A1, A2, A5, A6, A9 and A10 are the six corner points of the eaves and roof of the building respectively, A3, A4, A7 and A8 are different window corner points, A11 is the corner point of the side door edge, and A12 is the corner point of the steps.

In order to ensure the accuracy of the fusion model accuracy verification, this paper adds 8 groups of model side length accuracy verification in addition to the point accuracy verification, using the actual measurement length of the Leica-d2 laser rangefinder and the constructed fusion model to verify the accuracy results, selecting the side length, front width, building height, window width, front door width, step height, stone slab length and side door width of the ancient building model to compare with the actual laser rangefinder data respectively[9].

In this study, the error and the relative medium error are used to analyse the accuracy of the target object for comparison, and the average difference of six observation comparisons for eight objects of the 3D model of the building constructed in this study can be obtained from the comparison results$|\Delta S|_{Mean}$ 4.33 mm, 4.83 mm, 4.67 mm, 3.17 mm, 4.83 mm, 4.00 mm, 5.67 mm, and 4.50 mm, respectively, with an average error of 4.50 mm for the eight objects.

Next, the relative medium error δ is calculated as shown in Equation (5), which can be further calculated to verify the accuracy of each object.

$$\delta = \pm\sqrt{\frac{[\Delta\Delta]}{n}} \tag{4}$$

In equation (5), $\Delta = \Delta s$ and n is the number of observations. In this study, n is 6, and the relative error of the 8 objects of the 3D model of the building is 4.43 mm, 6.72 mm, 5.48 mm, 3.67 mm, 5.08 mm, 4.24 mm, 5.83 mm and 4.98 mm, and the average relative error of the 8 objects is 5.05 mm, which is in line with the first level error requirement of the mapping of the detail size of the single building of ancient architecture $(< 10\ mm)$. In summary, by the accuracy analysis of the point error and the relative medium error of the edge length, this study uses the improved feature point matching algorithm to achieve the construction of a complete 3D model of ancient buildings, and the model accuracy meets the requirements of 2D line drawing and modeling accuracy. In summary, by the accuracy analysis of the point error and the relative medium error of the edge length, this study uses the improved feature point matching algorithm to achieve the construction of a complete 3D model of ancient buildings, and the model accuracy meets the requirements of 2D line drawing and modeling accuracy.

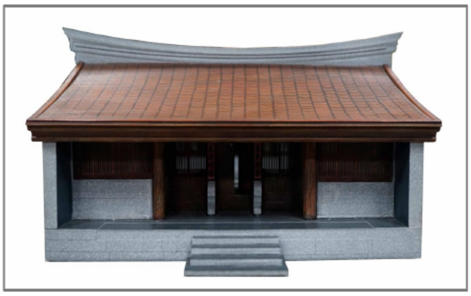
4 ENGINEERING DRAWING AND 3D DISPLAY APPLICATIONS

4.1 Model accuracy verification

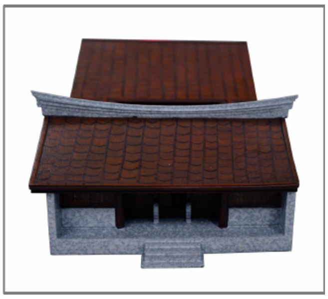
Based on the point cloud model, tilt model, and data model of multi-source data fusion obtained after data processing, information extraction of building plan and elevation is performed. Based on the high-precision point cloud model to extract two-dimensional information such as the internal elevation, external elevation, and internal building plan of ancient buildings; based on the tilt model to draw the plane slope of the area above the eaves of ancient buildings; the use of point cloud data and tilt data fusion of multi-source data model can extract the eaves and eaves of ancient buildings and other architectural detail information.

4.2 3D model printing of ancient buildings

The 3D modeling of ancient buildings mainly consists of the following steps: first, the individual elevation drawings extracted based on high-precision point cloud data are stitched together and white models are constructed based on the characteristic lines of the buildings. Next, texture mapping is performed on the white model to turn the model from a geometric solid to a true 3D model. In the process of data acquisition, the 3D laser scanner obtains image information from different angles of ancient buildings in all directions, and by texture mapping and rendering of the images, the texture picture effect reaches the best match with the model. The final 3D model of the ancient building after texture mapping and rendering is simultaneously available for display on the web platform. The approximate results are shown in the figure below in figure 5.



(a) Model scale (1:30)



(b) Model scale (1:130)

(c) Inside the model

Figure 5: 3D printed models of ancient buildings

5 CONCLUSIONS

In this paper, in order to obtain the complete model data of ancient buildings, we use the point cloud matching method to achieve the matching and fusion of ground 3D laser point cloud model and airborne LiDAR point cloud model to obtain the indoor and outdoor point cloud models of ancient buildings. Secondly, based on the improved feature point alignment algorithm, the fusion of 3D laser point cloud model of ancient building ground and tilt model data is proposed to obtain the complete model of ancient building, and it is verified that the accuracy of the fused model reaches centimeter level and meets the requirements of ancient building engineering mapping. Subsequently, based on the fusion model of ancient buildings, the line drawing of ancient building archiving project will provide the basis of architectural 3D spatial data for ancient building repair, planning and design, followed by the use of modeling and printing technology to reproduce the 3D physical miniature model of ancient buildings and make precious ancient building cultural and creative products, and finally, with the help of holographic interactive projection system, the original appearance of ancient buildings will be virtually reproduced to give the public more immersive and interactive experience about ancient building culture.

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