Research and Application of Model Fusion Based on UAV Tilt Photography and Three-dimensional Laser Scanner

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Abstract: In order to further study the method of model fusion, this paper uses UAV tilt photography technology and three-dimensional laser scanning technology to obtain the ground feature (building) information from the air and the ground respectively, and then used for model reconstruction. Firstly, the top and elevation point clouds of the building are generated by the UAV tilt photography technology and the point clouds of the building's elevation and bottom are acquired by the 3D laser scanner. After filtering out the noise correlation processing of the point clouds, the point clouds of the two are accurately integrated into a more complete building point cloud. Through the 3D reconstruction technology, the fusion point cloud is constructed into a building white model and then the texture map obtained by tilt photography of UAV is combined with the building white model. Finally, the reconstructed building model is obtained. This modeling method can make full use of 3D laser point cloud and UAV tilt photography image and make up for the limitation of 3D modeling of a single data source, which realizes more comprehensive and accurate reconstruction. Meanwhile, it can provide ideas for the research and application of model fusion by combining different tilt photography methods.

1. Introduction

The real and accurate 3D model has a very important application in urban planning, cultural protection and cultural tourism. However, 3D modeling based on a single data source has obvious limitations. For example, in the process of scanning a building with a 3D laser scanner, due to the restrictions of occlusion and scanning angle, the acquired point cloud of the building is not complete, most of which are the areas of the building's elevation and the ground. Therefore, only through the 3D laser point cloud on the ground to build the model will cause a large lack of the top plane, which will greatly reduce the integrity of the model. At the same time, the missing geometry and texture data affect the view of the whole model. At present, the latest UAV tilt photography modeling technology, due to the use of aerial photography, will also cause large-area voids and stretch problems in the production of the model because of the angle and the building's own shelter and other problems. In this respect, 3D laser scanning technology and UAV tilt photography technology can complement each other to achieve more comprehensive and accurate reconstruction.

In production practice, multi-source data synthesis is mainly used to model large-scale scenes and high-resolution models[1].

2. Data Collection and Processing

The experimental data is collected in Yanshan campus of Guilin University of technology. The main body of the model is the library of Guilin University of technology. The library was built and put into use in 2012, with a building area of 32000 square meters. Its size is equivalent to that of a museum in a second and third tier city. At the same time, because of the large scale of the library, it is also conducive to promoting to other large, medium and small buildings Universality. In this paper, the professional image processing software of Agisoft Metashape and the professional point cloud software of Geographic Studio are used to process the aerial image and the generated point cloud. The processing mainly includes: (1) tilt photogrammetry of UAV; (2) multi station laser scanning; (3) point cloud fusion; (4) model reconstruction. The specific technical route is shown in Figure 1.

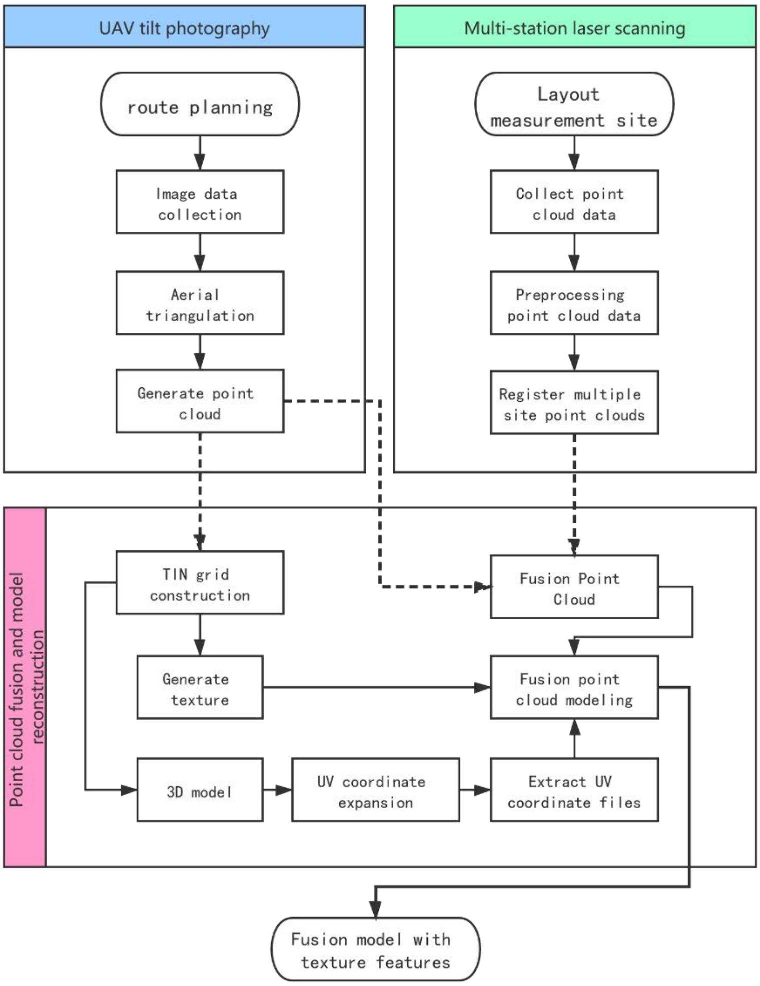

Figure 1: research technology route of model fusion based on UAV tilt photography and 3D laser scanner.

2.1. Acquisition and Processing of Ground 3D Laser Scanner Data

The vz-1000 3D laser scanner of RIEGL company was used in this study. This type of scanner is acclaimed to the advantages like long distance, high precision, speediness and portability, etc. The point cloud obtained by the scanner has a significant application in urban 3D modeling. Firstly, set the three-dimensional laser scanner up above the selected eight sites which is around the library one week along so that the cloud data of the facade and the bottom of the library can be collect completely. By means of the software called RIEGL LMS, basing on the first site, two neighboring sites are spliced with reflectors, supplemented by N-point alignment and other operations to carry out rough registration of point cloud. Finally, the nearest point control point in the objective function is iterated with the iterative nearest neighbor (ICP) algorithm to estimate the parameters of the transformation matrix, so as to minimize the registration error of the laser point cloud. The process of ICP algorithm registration point cloud is as follows.

For the two point clouds to be spliced by ICP algorithm, the corresponding point set P and Q are first established according to certain criteria, in which the number of corresponding point pairs is n. Then, the least square method is used to calculate the optimal coordinate transformation, that is, rotation matrix R and translation vector t, to make the error function minimum.

$$\mathrm{E}(\mathrm{R},\mathrm{t})=\frac{1}{\mathrm{n}}\sum_{k=1}^{\mathrm{n}}\|q^{k}-(R_{Pk}+t)\|^{2} \tag{1}$$

The algorithm is simple and intuitive, and can make the stitching have better accuracy. However, the running speed and convergence to the global optimum of the algorithm depend on the given initial transformation estimation and the establishment of the corresponding relationship in the iterative process to a great extent. Various coarse splicing techniques can provide better initial position for ICP algorithm, so it is the key to establish correct corresponding point set in the iteration process to avoid iteration falling into local extreme value, which determines the convergence speed and final splicing accuracy of the algorithm[2].

In the iterative calculation process, the change of the target function value of two iterations is less than a certain threshold value. After the iteration, the mean square error of the point cloud fine registration is controlled within the specified range, that is, the convergence is detected and ends. After 12 iterations, the final average distance is controlled within 0.638mm, and the standard deviation is controlled below 1.244mm which means the point cloud registration is basically completed, the iterative process is shown in Figure 2. Finally, the noise point cloud is removed by controlling the elevation display, and the irrelevant point cloud is filtered. The registration and noise removal results of all laser point clouds are shown in Figure 3.

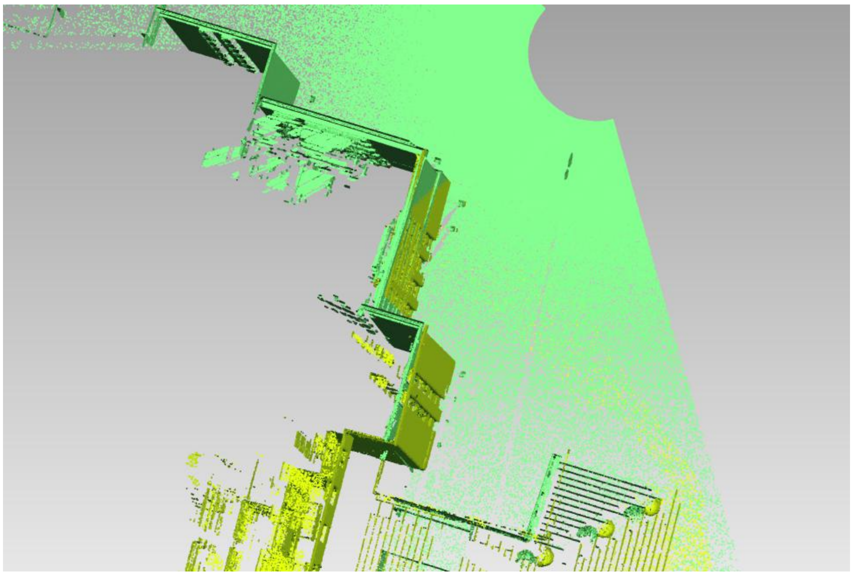

Figure 2: Iterative process of ICP algorithm for measuring station cloud.

Figure 3: Registration and noise removal results of all laser point clouds.

2.2. Acquisition of UAV Tilt Photography Data

The UAV (Mavic 2 zoom) was used to carry out Photogrammetry in five directions in the library in this study, four of which were tilt photography with a shooting angle of 45 ° to the flight route, and the fifth was orthophoto with a shooting angle of 90 ° to the flight route. In the route planning stage, set the course overlapping degree as 85%, side overlapping degree as 65%, 96 flight routes, and take 761 photos as tilt photography data. See Figure 4 for the route planning of tilt photography.

In this study, Agisoft metashape (photoscan), a professional UAV image processing software, is used to process UAV tilt photography. The most significant difference between metashape and traditional aerial photography software is that it uses the method of restoring three-dimensional scene (struc-ture from motion ,SFM) in motion information. The overall process of reconstructing the three-dimensional model of an object by SFM is as follows:

1) SIFT algorithm is used to extract feature points from each image and obtain their corresponding descriptors;

SIFT algorithm is an algorithm to extract local features of image by finding extreme points as key points in the difference of Gaussian DOG scale space and extracting different variables of scale, brightness and rotation[3].

2) According to the POS or other constraint relations, the image pairs that may have overlapping relations are selected;

3) The descriptors of each image are matched and the coarse error is eliminated by RANSAC algorithm;

4) According to the principle of computer multi-mesh vision, the homonymic image points matching each image pair are connected and unified. In the process of successive adjustment iteration, coarse differences are eliminated to estimate the relative positions of the camera and the sparse point cloud formed by matching points in the visual scene;

5) Combining the GPS of camera and the position coordinates of image control point, the real space position of camera and sparse point cloud can be obtained by using Damped Lead-Squares (DLS) algorithm[4].

For the sparse point cloud preliminary generated by SFM method, as initial value input, CMYS algorithm is used to cluster the image sequences according to the vision, then PMVS algorithm based on thousand micro patch model is used to diffuse these initial point clouds to the surrounding to obtain the spatial directed point cloud or patch, and dense reconstruction is completed under the constraints of local breadth consistency and global scope visibility. The number of reconstructed dense point clouds is 15715789, and the reconstruction results are shown in Figure 5. Export the reconstructed point cloud and prepare to merge with the point cloud obtain by three-dimensional laser scanner.

The dense point cloud is meshed from point to edge, from edge to face. It is based on the grid structure of triangular structure TIN. By generating texture and texture mapping, the model built by UAV tilt photography is established.

The texture mapping creates a specific texture mapping function to expand the three-dimensional texture details more specifically. There are two progressive mapping relationships in the generation process: one is from texture coordinate system to object coordinate system, the other is from object coordinate system to view coordinate system. The texture mapping process of these three coordinate systems also involves three space texture space, scene space and window space. This includes two mapping relationships: the mapping from texture coordinates to three-dimensional object coordinates and the mapping from three-dimensional object coordinates to screen window[5]. The model generated by tilt photography is imported into 3DS MAX to expand the UV coordinates (UV texture coordinates) and to export the texture coordinates and model textures. The exported model texture is shown in Figure 6.

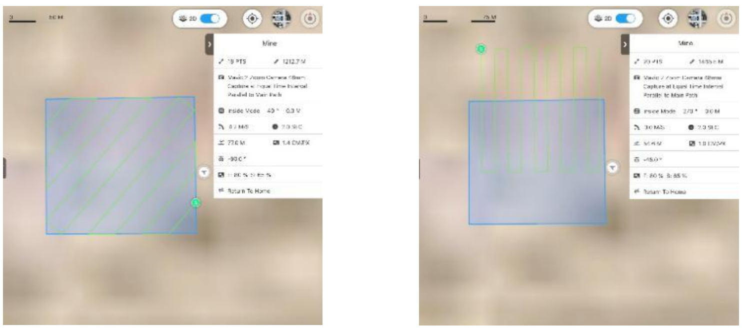

Figure 4: Route planning of partial orthophoto and tilt photography.

Figure 5: Slant point cloud reconstructed by tilt photography.

Figure 6: Exported model textures.

3. Point Cloud Fusion and Model Reconstruction

3.1. Fusion of UAV Tilt Photography Point Cloud and Three-dimensional Laser Scanner Point Cloud.

As the accuracy of three-dimensional laser point cloud after the splicing of each station is much higher than that of UAV oblique photogrammetry, the point cloud registered by three-dimensional laser scanner is the main part of the facade and bottom point cloud of the main body of the library, and the library and the top, the facade and the upper edge are mainly point clouds generated by oblique photogrammetry. For the point cloud of tilt photography, it also needs to be preprocessed by reducing the noise, removing the isolated points outside the body, determining the range of point cloud and cutting. At the same time, for the point cloud data spliced by the three-dimensional laser scanner, the redundant features in the scanning, such as the scanned point cloud information of pedestrians, vehicles and other point cloud, should be deleted. According to the overlap of the building point cloud and the laser point cloud in the tilt photography point cloud, the three-dimensional laser point cloud is used as the reference to find and match the same name control points in the oblique photograph point cloud through ICP registration algorithm. Finally the oblique photograph point cloud is accurately matched to the ground laser point cloud. Because of the different threshold and iteration times of ICP algorithm, the matching error is also different.

The comparison between manual registration and ICP global registration results of different iterations is shown in Table 1. ICP global registration results are much better than manual registration results. When the number of iterations is set to 20, the average distance and relative deviation are small, and the migration impact on three-dimensional reconstruction is small, which greatly improves the integrity and accuracy of the model.

After matching the tilt photography point cloud and laser point cloud, the point cloud with poor quality, over scanning and over offset will be displayed and deleted independently. For example, in the glass screen wall of the library, the following problems will occur:

1） Compared with the point cloud obtained by laser scanner, the offset of point cloud generated by tilt photography is too large. In three-dimensional reconstruction, the method based on tin TIN will cause large bulge and depression at the glass screen wall, as shown in Figure 7 below, which cannot reflect the real situation of the building;

2） Due to the strong penetration of the three-dimensional laser scanner to the glass, the internal structure information of the library is also clearly scanned, as shown in Figure 8 below, but this information will increase the amount of calculation in the process of three-dimensional reconstruction, and also lead to large area of depression in the model, which brings great uncertainty to the model reconstruction.

After the interference point cloud is displayed and deleted separately, the matching point cloud is synthesized into a fusion point cloud by using the joint point object tool to complete the fusion of the three-dimensional laser scanner point cloud and the UAV tilt photography point cloud. The results of point cloud fusion are shown in the following Figure 9 below.

Table 1: Comparison of ICP Global Registration Results between Manual Registration and Different Iterations.

Statistics \ Iteration	Manual Registration	20	40	80
Error	0.686	0.409	0.411	0.403
Average Distance	0.366	0.191	0.193	0.212

Iteration Unit : times Statistical Unit : mm

Figure 7: Bulge and depression after reconstruction of glass screen wall.

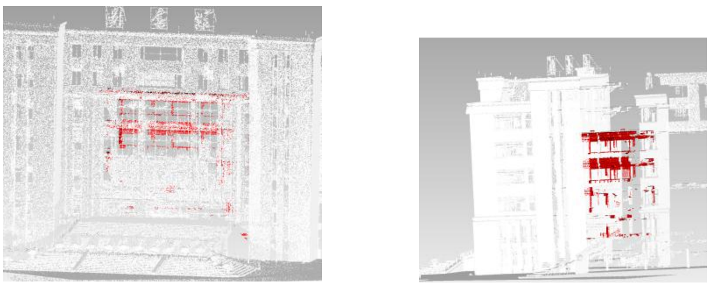

Figure 8: Library internal interference information (Marked in Red).

Figure 9: Fusion point cloud of Three-dimensional laser scanner and UAV tilt photography.

3.2. Three-dimensional Reconstruction of the Fused Point Cloud Model

The fused point cloud is again subjected to operations such as noise reduction tools and removal of outliers in vitro to further reduce the problem of darkening of sharp edges and roughening of smooth curves caused by noise. Adjusting the appropriate number of iterations and deviation threshold in the noise reduction tool can make the arrangement smoother and less noisy. The number of iterations is set to 3 and the deviation limit is set to 23mm. Taking a radical prism shape as a parameter, a subset of points Fit to shapes such as planes, prisms, etc. to obtain a smoother effect. The result of noise removal is shown in Figure 10 below. The amount of noise is shown in the color band area on the right side of Figure 10. From Figure 10, the noise of the fused point cloud is almost completely eliminated.

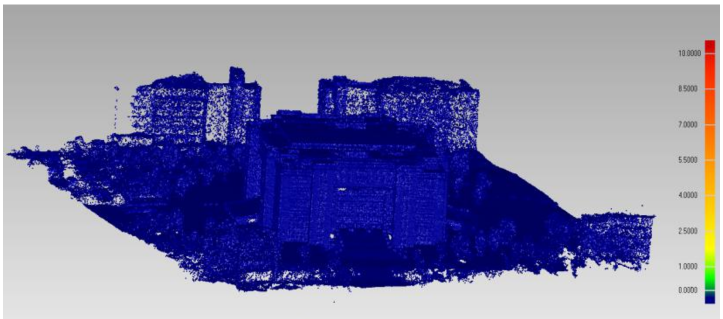

Figure 10: The result of noise removal.

For the area of the point cloud void, use the Fill Hole tool to insert ordered points into the gaps on the surface of the disordered point object to ensure that the generated 3D model does not have large voids. In the polygon stage, use the Fill Hole tool to create a new surface to fill the missing triangle mesh, but note that when using the Fill Hole tool at this time, you need to accurately select the hole edge area to ensure that the created surface will not interfere with other normal Use this tool with caution to further improve the integrity of the model. At the same time, use the feature removal tool and the mesh doctor tool to reduce the problems such as bumps and over-sags caused by abnormal point clouds. The "Polygon" command reduces the number of triangles in the model generation, especially the triangle mesh surface constructed by the top point cloud generated by the

UAV tilt photography. Finally, the encapsulation tool is used to generate a triangle model of the point cloud. So far, through point cloud encapsulation, the fused point objects are transformed into polygonal objects, and white molds of buildings and grounds are constructed to complete the basic operation of model reconstruction.

Mapping of the model texture Since both the model of the UAV tilt photography and the model generated by encapsulating the fusion point cloud have been cut, the original point cloud has been cut in the same range, and the cut part includes the connection point and the dense point cloud. Until the end, the overall shape, size, size, and area of the model constructed by the two methods are basically the same, but because the packaged model lacks UV texture coordinates and model texture, it is necessary to add the coordinates and texture derived from section 1.2.

The operation steps are as follows: 1) Import the fusion model into 3dxmax and expand its UV texture coordinates. The expanded texture coordinates are shown in Figure 11 .2) Add the texture coordinates exported in step 1.2 to the fusion model, and the exported UV textures are shown in Figure 12 .3) Add the fusion model with texture coordinates to Metashape, and import the model texture generated in step 1.2.

The above operation will complete the final step of 3D reconstruction by texture mapping of the model's white model through texture mapping. This study also tried to use the orthophoto of the UAV as the texture of the ground model. By selecting multiple feature points with the same name to achieve the accurate texture mapping of the orthophoto of the research area and the ground model, the "perspective crop" of Photopshop Picture, correct the image as an elevation orthophoto through tools such as "bevel", "deformation", etc., add the model texture[6] by mapping the top and side textures of the building to the corresponding model and output it, but due to the above operations It is too complicated, and it is necessary to use SLR camera to take the image of the building facade and classify the image according to the building. As a result, the fine texture generated by UAV tilt photography has not been fully utilized, but the combination of texture coordinates and model texture The method of texture mapping by the fusion model can effectively and fully combine UAV tilt photography and 3D laser scanning technology, while reducing the steps and increasing the accuracy of the model.

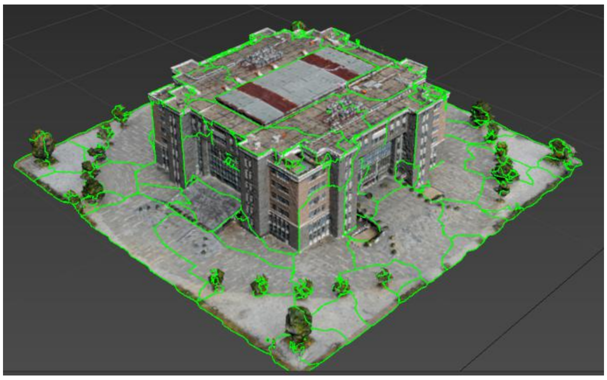

Figure 11: UV texture coordinates of the expanded model.

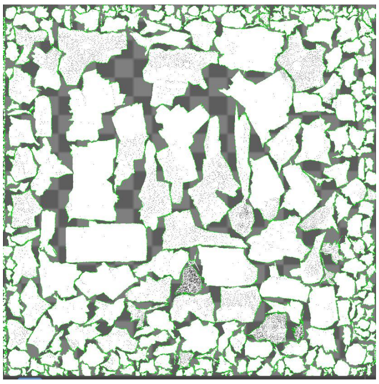

Figure 12: The exported coordinate texture.

4. Modeling Results and Applications

The results of the fusion point cloud reconstruction model are shown in Figure 13, which compares the UAV tilt photography model and the fusion point cloud reconstruction model as shown in Figure 14. Some have been significantly improved, but there are still some details that need to be repaired urgently. Using the MapGIS software as the basic platform to import the reconstruction models after texture mapping, in the MapGIS 3D geographic information platform, you can set up attribute tables for buildings and add attribute values to achieve 3D coordinate query, height measurement, and visibility analysis of 3D systems , Buffer analysis, sunshine analysis and other three-dimensional space analysis functions.

Figure 13: Result of reconstructed model fused with point cloud.

Figure 14: From left to right are the fusion point cloud reconstruction model and the tilt photography model.

5. Conclusions

The three-dimensional scene reconstructed by combining the ground three-dimensional laser scanning technology and the UAV tilt photography technology has greatly improved the accuracy and integrity of the three-dimensional reconstruction technology after absorbing the respective technical advantages of the two showing in three aspects.

1) The 3D laser scanner can collect the point cloud information of the facade and bottom of the house, and the UAV tilt photography can provide the point cloud data of the roof and facade of the building, which can be created by the combination of the two point cloud data The relatively complete building outline lays the foundation for the three-dimensional reconstruction of the building.

2) Extend the daily working hours. The work of the 3D laser scanner is not affected by time. It can work during the day and evening, and it is less affected by the weather than a single UAV tilt photography workflow.

3) Through the mapping of the model texture, the problem that the texture is difficult to obtain after the model reconstruction is solved. Compared with the top image and part of the facade image of the building collected by the UAV, a SLR camera is needed to supplement the shot The mapping of the model texture has the advantages of concise steps, simple operation and high precision.

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