Construction of Refined 3D Real Scene Models of Buildings based on Air-ground Integration Method

Fenghua LYU, Penghui DING, Baohua LIU

Key words: UAV oblique photogrammetry; SLR camera photogrammetry; texture and structure modification; historical buildings

SUMMARY

With the advancement of the construction of 3D Real Scene China, 3D real scene model data has become a new, unified and authoritative spatial digital twin base for the city. However, 3D Real Scene model is constructed from images taken from the air. Because of limitation of the occlusion between urban buildings, the near-ground parts of the buildings lack image information, resulting the problem of texture distortion and structural deformation in the construction of the 3D real scene model of the near-ground part of a building. In order to solve the above problems, this paper proposes an air-ground integrated refined 3D real scene modeling method, in which method a UAV with an oblique camera is firstly used to obtain ground oblique images, and then a SLR camera on the ground is used to take surrounding supplementary shots of each building. During the shooting process of the SLR camera at each site, images of the building from 5 angles are obtained. For facade information, the UAV oblique images and ground SLR images will be collected to perform aerial triangulation adjustment to obtain dense matching points, and finally a refined 3D real scene model of the building is constructed. Taking the Qingdao Bookstore, a historical building in Qingdao, as an example, a DJI UAV is firstly used to obtain oblique image information of the building from the air, and then a Sony SLR camera is used to capture the building facade images on the ground at a certain distance, and then aerial triangulation adjustment is performed. Finally, a 3D real scene model of the building is constructed. Compared with the 3D real scene model of Qingdao Bookstore by using UAV oblique images, the air-ground integration method proposed in this paper obtains 3D real scene model with more clear texture near the ground and under the eaves, with a reasonable structure, consistent with the real situation of the building. The results show that the method proposed in this paper effectively solves the problem of texture embroidery and structural deformation issues. At the same time, the proposed method is simple and easy to implement, with less manual intervention and a higher degree of automation in the entire construction process.

SUMMARY

随着实景三维中国建设推进，实景三维模型数据已成为城市新的、统一的、权威的空间数字孪生底座。但实景三维模型是空中对地面拍摄的影像构建而成，受限于城市建筑物之间遮挡，缺少建筑物近地面部分影像信息，造成建筑物实景三维模型近地面部分存在纹理拉花和结构变形问题。为有效解决上述问题，本文提出了空地一体化精细化实景三维建模技术。该技术首先通过无人机搭载倾斜相机获取地面倾斜影像，然后在地面利用单反相机对每一栋建筑物进行环绕补拍，每站点单反相机拍摄过程中模拟倾斜相机从 5 个角度获取建筑物的立面信息，将采集到无人机倾斜影像和地面单反影像一同开展空三计算获得密集匹配点，最后

构建出精细化建筑物实景三维模型。以青岛市历史风貌建筑物青岛书屋为例，利用大疆无人机从空中获取建筑物的影像信息，然后利用索尼单反相机按照一定距离在地面拍摄建筑物立面影像，然后进行空三计算，得到建筑物实景三维模型。对比仅利用无人机倾斜影像构建青岛书屋实景三维模型，本文提出的空地一体化技术得到实景三维模型近地面和屋檐下部分纹理清晰，结构合理，符合建筑物真实情况，有效解决了纹理拉花和结构变形问题。同时，本文提出的方法简单易行，整个构建流程人工干预少，自动化程度高。

1. **Introduction**At present, the methods of building 3D model reconstruction are mainly divided into three categories: artificial 3D modeling, reverse 3D reconstruction based on 3D laser scanning technology, and oblique photography to reconstruct real-life 3D models[1]. Manual three-dimensional modeling technology mainly uses 3ds Max, UG, Revit, and AutoCAD to manually produce three-dimensional models. The results of this modeling method are relatively free, the amount of data is small, and it is easy to query and call. However, it requires a lot of human-computer interaction, has a long cycle, is low in efficiency, and the accuracy completely depends on the accuracy of measurement and two-dimensional drawings. Three-dimensional laser scanning reverse modeling technology is a technology that obtains object surface point cloud data and then uses reverse modeling software to build a three-dimensional model[2]. This method has high work efficiency, less manual intervention, and high model accuracy. However, this method is difficult to use on a large scale due to expensive equipment and the need to deploy multiple stations to collect data. Oblique photogrammetry technology is a high-tech technology developed in the field of international surveying, mapping and remote sensing in recent years. By carrying multiple sensors on the same flying platform, it collects images from different angles such as vertical and oblique at the same time to obtain more complete and accurate information about ground objects. The collected images are then processed through area network adjustment, multi-view image dense matching, three-dimensional TIN network construction, and texture mapping to generate a real-life three-dimensional model[3]. This method has the characteristics of model close to the real environment, high accuracy and rich texture. This model provides a unified digital space base for the construction of digital twin cities in urban planning, emergency command, traffic management, cultural relics protection, etc[4].

However, due to the high height of the flying platform when acquiring images, and the mutual occlusion between buildings and trees and buildings in urban areas, oblique photography technology cannot completely obtain the geometric and texture information of near-ground objects. Real-life 3D models of ground objects often appear blurry, smeared, and broken, which reduces the quality and accuracy of the model[5]. In order to improve these shortcomings of the real-scene 3D model of oblique photogrammetry, the construction method of refined real-scene 3D model has become a research hotspot. At present, many scholars are studying the use of ground shooting methods to make up for the problems of oblique photogrammetry technology, which are generally divided into methods of shooting images near the ground, such as using UAVs to obtain near-ground images[6], using SLR cameras or a combination of multi-lens cameras The positioning device provides near-ground image POS information[7-10]. This type of method places higher requirements on ground shooting equipment. The image information of ground supplementary shooting must contain POS information to assist in later aerial triangulation, otherwise the aerial triangulation will fail; or the object can be obtained through a three-dimensional laser scanner. The near-ground point cloud information is combined with the wide-angle SLR camera for feature matching, and the dense point cloud obtained by oblique image matching is fused together, and finally a TIN network is constructed for texture mapping. The processing process of this type of method is complex, and the coordinate systems of multi-source data need to be unified, which puts forward higher requirements for the accuracy of control point data. Otherwise, it is easy to cause stratification during the aerial triangulation stage. This type of method is mostly used for three-dimensional modeling of ancient buildings[11-13]. In addition, many scholars combine computer vision and close-range photogrammetry theory to optimize traditional aerial photography shooting points and shooting angles, and propose methods of optimal view photogrammetry[14-16]. This method first obtains the DSM information of the area, and plans the shooting point and shooting camera angle based on the DSM information. This method greatly reduces the number of images, improves the modeling efficiency, and also improves the model expression effect. However, it is limited by UAVs. Operational safety, this method has not completely solved the problem of lack of near-ground image information, and this type of method needs to obtain DSM data in the area for waypoint planning, which is cumbersome to operate.

This article summarizes the research experience of the above-mentioned scholars and proposes a refined model construction method for open-ground integrated buildings. This method first uses a UAV to obtain images perpendicular to the ground, and then uses a SLR camera to capture images around the building on the ground. In order to facilitate later aerial triangulation, a UAV is used to capture images of the building facades around the building, and then all the The images are subjected to aerial triangulation, multi-view images are densely matched, a TIN is constructed, and finally texture mapping is performed to obtain a refined real-life three-dimensional model. The advantage of this method is that it does not require high equipment and only requires a SLR camera and a UAV; it is simple to operate; has a high degree of automation, and does not require the selection of additional connection points. It is basically consistent with the traditional oblique photogrammetry modeling method.

2. Methodology

This method is divided into three stages. The first stage is the field image collection stage, which mainly uses UAVs and SLR cameras to obtain building image information. The UAV is divided into aerial photography of buildings to obtain the influence of the aerial perspective. The UAV There are two ways to obtain building facade images by surrounding the building. The SLR camera surrounds the ground of the building to obtain the ground perspective image of the building. The second stage is the in-house aerial triangulation stage. The above-mentioned acquired images are imported into the 3D modeling software to carry out aerial Triangulation is to obtain dense point cloud information through dense matching of multi-view images. The third stage is the model construction stage. The dense point cloud is used to construct three-dimensional TIN information to obtain white model information, and then texture mapping is performed to finally obtain a refined real-life three-dimensional model. Specifically See Figure 1.

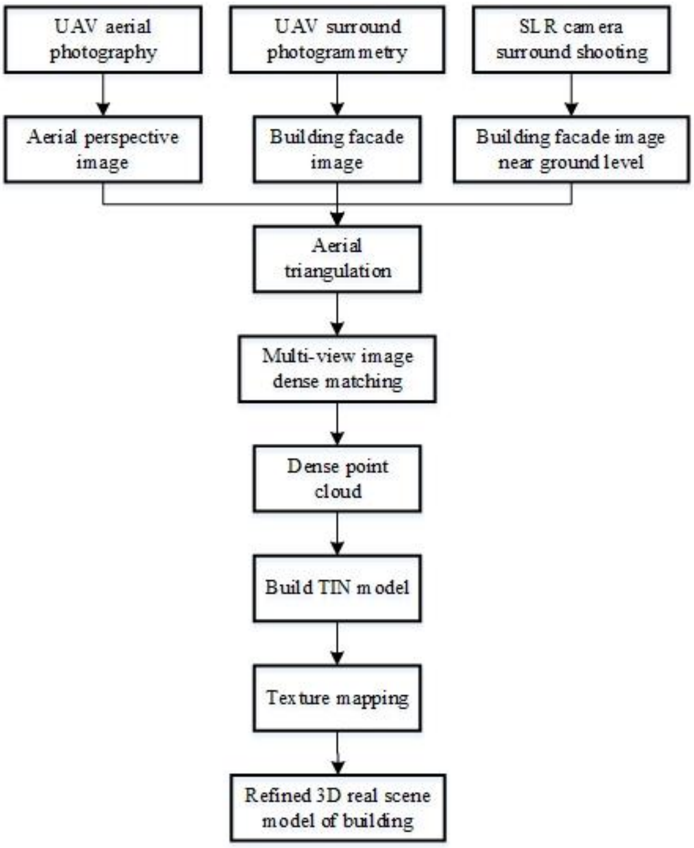


Figure 1 Flowchart of refined 3D modeling method for open-ground integrated buildings

2.1 Air-ground integrated data shooting

2.1.1 UAV Aerial Photography

UAV aerial photography follows the technical specifications for real-life three-dimensional model construction. During route planning, the altitude, resolution, course overlap, and side overlap are set according to the on-site operating environment. Carry out UAV aerial photogrammetry in accordance with this requirement. I won't go into too much detail here in this article.

2.1.2 SLR ground surround photography

In order to solve the problems of texture loss, blur and deformation in the near-ground area of the real-life 3D model, a SLR camera is used to surround the building on the ground to obtain the facade image. The specific shooting method is shown in Figure 2.

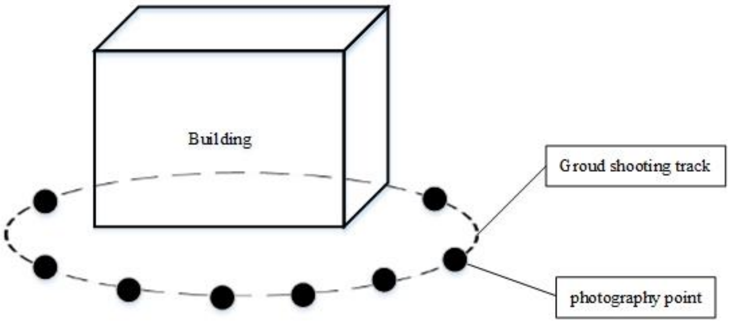


Figure 2 Schematic diagram of the SLR surround shooting method of a building

At each shooting point, this article proposes to use a SLR camera to simulate a five-lens tilt camera shooting method to obtain building facade information from the "top-middle-bottom" and "left-right" angles, and to obtain the building eaves from the "top" angle. The image below supplements the fact that it is impossible to shoot from the air due to the eaves blocking it; the "middle" image is perpendicular to the building to obtain the image of the building's facade, and performs aerial triangulation with the UAV's surrounding shooting; the image captured in the "bottom" supplements the combination of the building and the ground Part of the information; "left" and "right" shooting images ensure the overlap of image information between adjacent shooting points, which facilitates later aerial triangulation. The shooting method of each shooting point is shown in Figure 3.

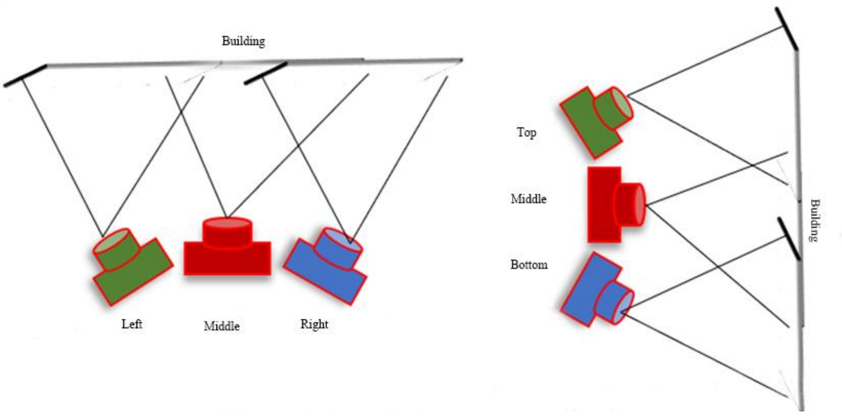


Figure 3 Schematic diagram of the simulated tilt camera shooting method at each shooting point (the "middle" shooting is the same photo)

During SLR shooting, you need to pay attention to the following points:

(1) According to the distance between the UAV and the building facade when the UAV shoots the

facade, determine the shooting distance between the SLR camera and the building. During the shooting process, try to control the shooting position and the distance between the building and the building to be as fixed as possible. distance to avoid problems that are too far or too close;

(2) During the single-station shooting process, take 5 pictures at each station, that is, top, middle, bottom, left, and right, similar to shooting with a tilted five-lens camera. During the shooting process, pay attention to keep the overlap of the photos taken at all angles to meet the requirements, among which The left, middle and right should be shot at the same height as much as possible, and the overlap between them should be more than 70%. The top, middle and bottom should be shot in pitch and orthophoto, and the overlap should be controlled at more than 60%;

(3) During the single-station shooting process, when taking five photos, the angle of each photo should not be too large, and the angle should be controlled below 15°;

(4) In order to reduce the workload of later in-house data processing, during the field data collection process, the number of collected photos should be reduced as much as possible while ensuring a certain degree of overlap.

2.1.3 UAV Surround Photography

Since the information obtained by UAV aerial photography is to obtain the object image from an aerial perspective, while the SLR camera obtains the object image from the ground, the difference between the two is too large in terms of shooting angle and resolution, making it difficult to obtain the same name in the later aerial triangulation process. point, thus causing aerial triangulation to fail. Many scholars have proposed adding connection points to assist aerial triangulation. However, due to limitations in shooting angle and resolution, even adding connection points will not be of much help to later aerial triangulation. The possibility of aerial triangulation passing will not be greatly improved. At the same time, the connection points The selection also has a direct impact on whether the pass rate of aerial triangulation can be improved, which places higher requirements on the technical experience of later industry personnel and reduces the feasibility of the method.

Based on the calculation principle of the same point in aerial triangulation, this paper proposes a method of using UAVs to surround and close to the photogrammetry. According to the requirements of the technical specifications for real-scene three-dimensional modeling, while ensuring the degree of overlap, the UAV is used to surround the building at different locations. First adjust the height of the UAV camera to tilt it at an angle of 45° to obtain the facade information of the building. Then gradually reduce the height of the UAV and adjust the angle of the UAV camera to 90° perpendicular to the facade of the building to obtain the facade information of the building. , the images taken at different heights should maintain a certain degree of overlap. The specific shooting method is shown in Figure 4.

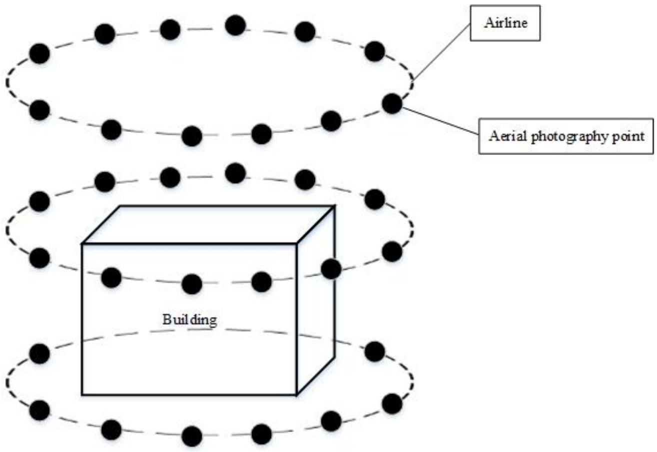


Figure 4 Schematic diagram of the UAV circling close to the photography path and aerial photography points

In the image shooting angle, there is an effective transition from perpendicular to the ground, to shooting at an angle of 45 degrees, to shooting at 90 degrees perpendicular to the building facade, to avoid aerial triangulation failures caused by excessive changes in shooting angles. In terms of image resolution, the building facade image obtained through surround close photogrammetry maintains consistency with the ground surround shot, improving the pass rate of aerial triangulation.

2.2 Aerial Triangulation

Aerial triangulation refers to the use of photogrammetric analysis to determine the exterior orientation elements of all images within an area. In traditional photogrammetry, this is achieved by measuring point positions, that is, based on the coordinates of the image points measured on the image and the geodetic coordinates of a small number of control points, the geodetic coordinates of the unknown points are obtained, so that the known points are increased to There are no less than 4 in each model, and then these known points are used to solve the external orientation elements of the image. Therefore, analytical aerial triangulation is also called photogrammetry encryption or aerial triangulation encryption.

The beam method area network aerial triangulation uses a beam of light composed of a photo as the basic unit of adjustment, and uses the collinear equation of the center projection as the basic equation of adjustment. Through the rotation and translation of each light beam in space, so that the light rays of the common points between the models can achieve optimal intersection, and the entire area can be optimally incorporated into the known control point coordinate system, so that the coordinates of the common intersection points of adjacent photos are equal and the control points are internal On the condition that the coordinates are equal to the known field coordinates, the error equations of the control points and the encryption points are listed, a unified adjustment calculation of the entire area is performed, and the external orientation elements of each photo and the ground coordinates of the encryption points are solved. For current fully automatic aerospace triangulation software, images are generally used to automatically match heading and side image points, and all flight belt networks in the entire area are integrated into a coordinate system with a unified scale to form a loose regional network. Confirm the approximate position of the external orientation elements and ground point coordinates of each photo, and then establish error equations and modified method equations point by point based on the field control points to solve for the external orientation elements of each photo and the ground of the encrypted points. coordinate. After obtaining the approximate values of the external orientation elements of each photo and the ground coordinates of the encryption points, the collinear condition equations can be used to list the error equations of the control points and encryption points on each photo[17-19]. The following two relations can be listed for each image point, namely:

$$\begin{cases} x - x_0 = -f\dfrac{m_1(X_A - X_S) + n_1(Y_A - Y_S) + u_1(Z_A - Z_S)}{m_3(X_A - X_S) + n_3(Y_A - Y_S) + u_3(Z_A - Z_S)} \\ y - y_0 = -f\dfrac{m_2(X_A - X_S) + n_2(Y_A - Y_S) + u_2(Z_A - Z_S)}{m_3(X_A - X_S) + n_3(Y_A - Y_S) + u_3(Z_A - Z_S)} \end{cases}$$

In the formula, $x0$、$y0$、f are orientation elements within the image;（x, y）are the coordinates of the image point in the image plane;（X_S，Y_S，Z_S）are the coordinates of the target point A in the object space;（X_A, Y_A, Z_A）are the coordinates of the camera point A in the object space; (m_i, n_i, u_i)（i=1,2,3）are the cosine values composed of the three outer azimuth elements of the image.

2.3 Texture Mapping

After aerial triangulation, a densely matched point cloud is obtained, and then the densely matched point cloud is constructed into a TIN, and finally texture mapping is performed. The so-called texture mapping is the process of mapping texels in texture space to pixels in screen space. The calculation process is to obtain the screen projection space coordinates after transforming the vertices of the TIN model, and the triangles in the model are converted from model space coordinates to screen space coordinates. After the fragments are clipped off-screen, they are rasterized to form small fragments (pixels). Each fragment contains a texture coordinate derived from the difference between each vertex. In the pixel coloring stage, the color value can be obtained by sampling the specified texture through the texture coordinates of the fragment and used as the color of the fragment. Finally, each fragment in the TIN model obtains a color value to realize the texture mapping of the model [20-22].

3. Experiments and Results

3.1 Experimental area and data acquisition

This article selects the historical style building of Qingdao Study Room (also known as Anna Villa) in Qingdao City, Shandong Province as the research object. This building is located on the southwest side of the intersection of Qufu Road and Zhejiang Road, Shinan District, Qingdao City. It was first built in 1901 and completed in 1903. It is a typical Baroque architecture. The builder and first owner was German businessman Robert Kapler. The brick and tile manufacturer named the new home Villa Anna in memory of his beloved daughter.

Figure 5 Real photos of Qingdao study room

The field collection equipment for this article includes a DJI Phantom 4 UAV and a Sony Alpha 7 SLR camera. The DJI Phantom 4 UAV was used for aerial shooting to obtain 104 photos, with a photo resolution of 5472 pixels * 3648 pixels; the DJI Phantom 4 UAV was used for close-up and surround shooting to obtain 286 photos, with a photo resolution of 5472 pixels * 3648 pixels. ; Use Sony Alpha 7 SLR camera to capture 2025 photos around the building on the ground, with a photo resolution of 6000 pixels * 4000 pixels

3.2 Results and Analysis

3.2.1 Initial 3D Real Scene Model

Use ContextCapture software to process 104 aerial photos taken by UAVs, conduct aerial triangulation, and then build a real-life three-dimensional model. Figure 6 shows the aerial triangulation results. Figure 7 is the initial real-life 3D model effect.

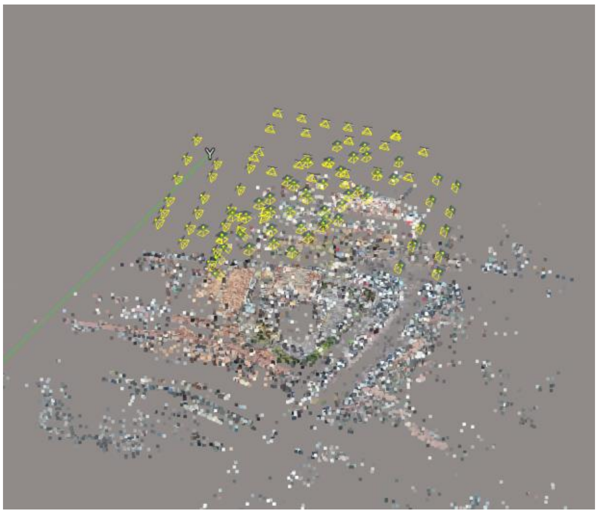


Figure 6 Aerial triangulation results of UAV aerial images

Figure 7 3D Real Scene Model rendering of UAV aerial images

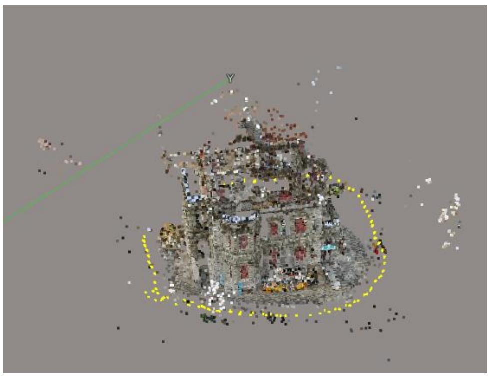
From the initial modeling results, it can be found that the overall performance of the model is good, the ground elements are complete, and the macro texture can be expressed more intuitively. However, affected by factors such as aerial perspective occlusion, light shadows, and glass curtain walls, the model is blocked close to the ground and high in the sky. There are phenomena such as texture loss, blur, aliasing, and holes in ground objects. As shown in Figure 8, due to the obstruction of building eaves and billboards, the image of the building cannot be obtained from the aerial perspective, causing the model to have blurred textures and wavy patterns.

Figure 8 UAV aerial image reconstruction model problem

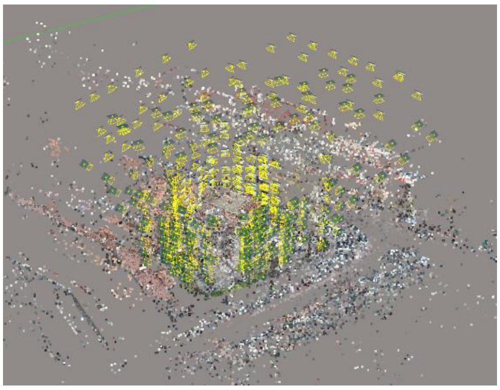
3.2.2 Air-ground Fusion Model

This paper uses three aerial triangulation solutions for air-ground fusion: (1) UAV aerial images and ground SLR images are directly fused for aerial triangulation;(2) UAV aerial images and UAV surround images are directly fused for aerial triangulation;(3) UAV aerial images, UAV surround ~~images and ground SLR images are fused for aerial triangulation. This solution is the fusion method~~ proposed in this article.

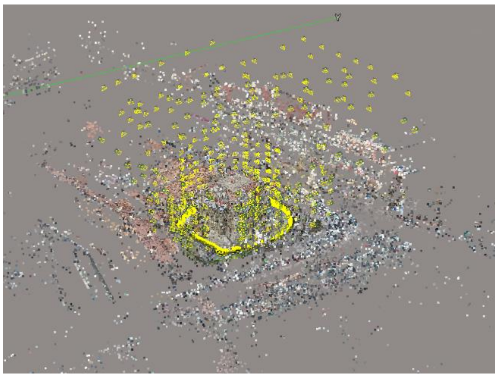
Solution(1): Ground SLR images and aerial images cannot extract enough feature points with the same name, ground images and aerial images cannot be matched, UAV aerial images and some ground SLR images are not matched successfully, the aerial triangulation solution result is shown in Figure 9 (a) is shown. Solution(2) The UAV aerial image and the close surround image are successfully matched, and the aerial triangulation solution result is shown in Figure 9(b). Solution(3) After adding the close surround image, the UAV aerial image and the ground SLR image were successfully matched together. The aerial triangulation solution result is shown in Figure 9(c).



（a）Solution(1)



（b）Solution(2)



（c）Solution(3)

Figure 9 Aerial triangulation results of three fusion schemes

After texture mapping, select the original model, fusion plan 2 to build the model and fusion plan 3 to build a three-dimensional model, and select 4 representative areas under the eaves, windows, billboards, and porch areas from the model texture clarity, whether to draw flowers, The quality of the model is analyzed whether there are holes, and the results are shown in Figure 10.

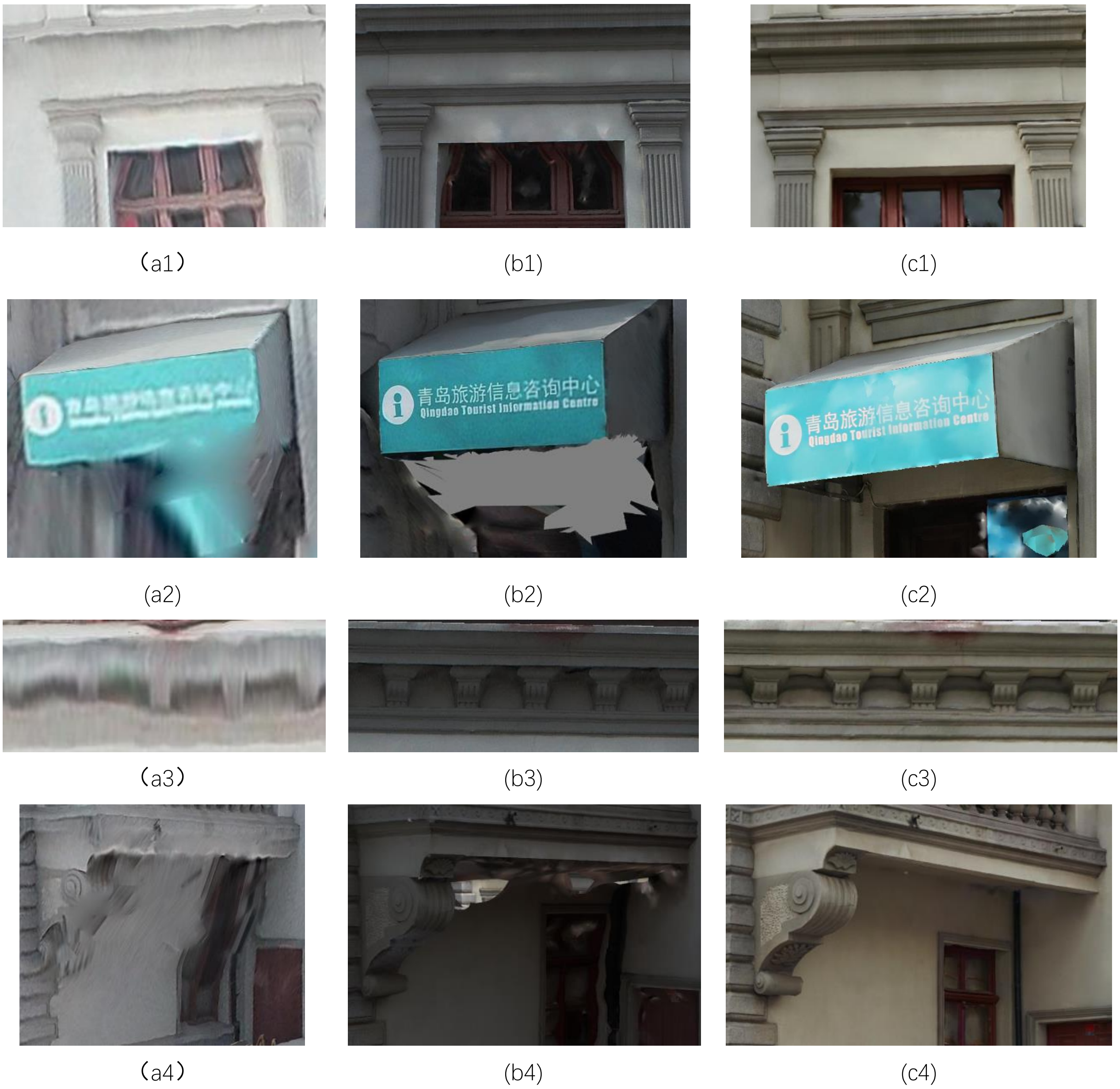


Figure 10 Comparison of the modeling effects of the three models. (a1) (a2) (a3) (a4) is the original model rendering; (b1) (b2) (b3) (b4) is the plan 2 model rendering; (c1) (c2) (c3) (c4) is the modeling renderings of the fusion method in this article; (a1) (b1) (c1) is the modeling renderings of the building window area; (a2) (b2) (c2) is the modeling renderings of the building billboard area; (a3)) (b3) (c3) is the modeling rendering of the eaves area of the building; (a4) (b4) (c4) is the modeling rendering of the porch area of the building;

From the comparison of model renderings, compared with the original model, the model built in Scheme 2 has been greatly improved in terms of texture clarity and model drawing. However, the model built in Scheme 2 has texture missing in local areas (as shown in the figure). 10 (b2)), model embroidery (Figure 10 (b2)) and holes (Figure 10 (b4)). In addition, due to different shooting angles and different lighting conditions, the model constructed in Scheme 2 has certain shadow and spot problems (Figure 10 (b1)). Therefore, in terms of the quality of texture details, it can be found from the comparison of various modeling effects in Figure 10 that the method in this paper is better than the other two methods in building models in terms of geometric structure, spatial relationship and clarity of detailed textures. In areas such as downstairs, corridors, billboards, windows, etc., the images shot around the ground effectively make up for the distortion, deformation, texture loss, holes and other problems of part of the building structure caused by the occlusion in the above areas. The constructed three-dimensional model has lower geometric distortion, the expression of texture details is more intuitive, delicate and clear. However, due to the high resolution of ground surround shooting images, there are few matching points with the same name in a single texture area when compared with UAV aerial and surround images, resulting in holes in some single texture areas. But to sum up, the real-life 3D model established by this method has better texture quality and better modeling effect.

3.2.3 Analysis of Experimental Results

The method in this paper and the traditional method have significantly improved the fusion effect of aerial triangulation, the overall effect of the model and the expression of texture details.

(1) It effectively reduces the difficulty of air-ground integration. There is no need for additional manual selection of connection points during the aerial triangulation calculation process. It is simple to invest in equipment and the overall method has certain generalizability;

(2) The fusion modeling of ground surround shooting images effectively makes up for the problems such as embroidery, deformation, holes and blurred textures of the model from the aerial perspective. The texture expression of the model is clearer and the effect is more realistic;

(3) This article proposes a ground surround shooting method, which effectively reduces the problem of shadow spots after the fusion of space and ground.

At the same time, the method proposed in this article also has the following problems:

(1) In a building with a single local texture, such as a solid color texture area, the method constructed by this article has a hole problem;

(2) The problem of calculation error in aerial triangulation of open space and ground fusion in some areas, resulting in model texture mapping errors.

4. Conclusion

This paper proposes a method for 3D modeling of real-life buildings with integrated space and ground. It uses a SLR camera to simulate a five-lens tilt camera shooting method to obtain the ground perspective image of the building, the aerial perspective of the UAV, and the surrounding close perspective image data for fusion modeling. This method is simple to operate, has low equipment requirements, effectively reduces the difficulty of air-ground integration, and solves the problems of missing textures, holes, and model embroidery in areas such as eaves, billboards, and porches of a single aerial perspective real-life 3D model. The historical buildings in Qingdao were selected as the experimental area to verify the ability of this method in refining the real-life three-dimensional modeling of historical buildings. Experimental results show that compared with traditional methods, the method in this paper has the advantages of good model effect, clear texture, and richer details. It achieves the complementary advantages of multi-view and multi-level images of open space and further improves the expression of real-life three-dimensional models. The effect is of great significance to the production of real-life three-dimensional model digital products and the multi-scale expression of spatial data, and provides a more sophisticated digital model for the digital management of historical buildings.

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BIOGRAPHICAL NOTES

LYU Fenghua, Ph.D. in Engineering, national registered surveyor, senior engineer. Mainly engaged in UAV aerial remote sensing, real-life 3D model refinement and integration, and InSAR subsidence monitoring.

CONTACTS

Title Given name and family name:Dr. Fenghua LYU

Organisation: Qingdao Surveying & Mapping Institute

Address: No. 189, Shandong Road, Shibei District, Qingdao City, Shandong Province

City:Qingdao

COUNTRY:China

Tel.: +86:15063985630

Email:fenglvhua@163.com