Research on UAV Oblique Photography Route Planning in the Investigation of Building Damage after the Earthquake

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Abstract. The post-earthquake building damage investigation is an important part of the earthquake emergency rescue work. It is a prerequisite for the ability to determine the location of the buried people and rescue the victims in the shortest time. Therefore, the timeliness of the post-earthquake building survey is a significant factor. The 3D reconstruction model of buildings based on UAV tilt photography has the advantages of multi-angle and three-dimensional, but it is too time-consuming. Therefore, this paper proposes a UAV tilt photography route planning algorithm. This algorithm improves the efficiency of the three-dimensional reconstruction of the building and saves valuable time for emergency rescue work. The algorithm requires two drone flights. During the first flight, the drone flies horizontally to get the aircraft POS data. With the POS data, the corresponding feature points on the ground will be obtained. According to the clustering of the feature points, the building oblique photography path planning area will be generated. Finally a reasonable drone route planning will be produced. During the second flight, the flight route generated by the algorithm was used to take oblique photography of the building to produce a three-dimensional reconstruction model. The final building model will be obtained based on the combination of the models obtained from the two flights. After contrast experiments with traditional oblique photography, the algorithm in this paper is significantly superior to the traditional oblique photography method in terms of building 3D reconstruction efficiency.

1. Introduction

It is always a time-consuming, and laborious job to conduct field surveys of large-scale building damage after an earthquake, which is against the requirements of post-earthquake emergency rescue. We need to find a way to get a snapshot of a large number of collapsed houses so as to save manpower and resources. Compared with traditional aerial photogrammetry and manual field survey, the 3D reconstruction of buildings based on drone tilt photography has the advantages of multi-directional, three-dimensional, and rapid, which can meet the needs of rapid building loss survey work after the earthquake. Therefore, UAV tilt photography is very useful for surveying large-scale building loss after the earthquake. Xu Jianhua¹ used the drone tilt photography technology to construct a three-dimensional model of the building during the Jiuzhaigou M7.0 earthquake, and used measurement tools to obtain the actual size of the damaged target, providing a new method for post-earthquake building surveys. During the same period, Yuan Xiaoxiang² used Zhangzha Town and Heyezhai in the Jiuzhaigou M7.0 earthquake-stricken area as the survey sample areas. According to the remote sensing seismic damage index, the three-dimensional model of UAV aerial photography was used to quantitatively evaluate the remote sensing loss in the study area, and further reduce the damage. Error in building loss assessment. Zhao
Jie[3] designed and developed the UAV emergency rescue subsystem, and provided support for the post-earthquake disaster collection by using the 3D model of oblique photography. Chen Jinhong [4] developed a UAV-based image analysis method for earthquake areas, which inspected the quality and texture of objects such as buildings in the earthquake area, and performed support vector machine classification on the three-dimensional images to obtain the damage degree of the buildings. Innovate the building damage index to evaluate the degree of damage to buildings caused by earthquakes. Styliani Verykoko [5] uses drone tilt photography to perform 3D reconstruction of damaged buildings to ensure the rapid progress of urban emergency search and rescue work and improve the survival probability of buried personnel. Zhang Ruiji [6] used UAV tilt photography and infrared thermal imaging technology to extract the damage information of buildings after the earthquake, and based on this model, simulated earthquake search and rescue scenes to verify the reliability of the program.

The above-mentioned studies are classic cases of UAV oblique photography 3D reconstruction technology to model and investigate buildings after an earthquake. Meanwhile, the coverage and timeliness of UAV oblique photography for post-earthquake building surveys are two significant factors. Arman Nedjati [7] proposed the use of multiple drones to collect on-site seismic damage images and perform three-dimensional modeling. Based on the network coverage problem, a linear enhancement technology is proposed, and the flight path is optimized for the three-dimensional modeling of the UAV, and the optimal path is obtained. Marina Torres [8] is based on the line sweep calculation theory (line sweep calculation) to improve the flight line by using the coverage replacement of the flying polygon area and the flight path interruption strategy to meet the maximum coverage while reducing the flight distance, thereby speeding up the 3D modeling speed. Zheng Xiaoci [9] uses fixed parameters to determine the initial flight route of the UAV, and optimizes the depth of the route according to multiple constraints, which improves the efficiency of 3D modeling to a certain extent. Neil Smith [10] used heuristic methods to develop a set of continuous optimization algorithms for small UAVs. Under the premise of ensuring the accuracy and completeness of the three-dimensional model, the optimal flight path was calculated to greatly shorten the flight time. Yan Feihu [11] proposed a UAV path optimization algorithm that automatically generates a priori data of a 3D model. The algorithm generates a 3D lattice with restricted conditions based on the complete coverage of the prior model, and connects an optimized path through a smoothing algorithm, which has significantly improved the performance of 3D reconstruction.

Different algorithms for building 3D reconstruction coverage and timeliness optimization have their respective advantages. The above-mentioned methods all require complex calculations and path optimization. Although the accuracy of building 3D reconstruction is improved to some extent, the response-time criterion for loss investigation for post-earthquake buildings appear to be very high. Therefore, we propose a fast route planning algorithm for UAV tilt photography, which is able to complete the three-dimensional reconstruction of the building in a short time and still meet the coverage accuracy of the building.

2. Fast clustering path planning method of terrain feature points based on POS data

The UAV oblique photography fast path planning algorithm is divided into four parts, namely, UAV POS data preprocessing, terrain feature point generation, feature point clustering and path division (Figure 1). The UAV POS data includes the UAV’s latitude and longitude in the air and the UAV’s azimuth and attitude angle. By correcting the POS data, more accurate latitude, longitude and azimuth attitude information is obtained, and the latitude and longitude elevation data of the corresponding feature points are calculated through the collinear theoretical equation. Perform k-means clustering on the elevation scatter data, that is, terrain feature points to obtain the building area, and delineate the building’s three-dimensional oblique UAV path area according to the lens tilt angle, thereby generating the UAV flight path.
2.1. POS data preprocessing

When the drone is taking photogrammetry, its positioning system (POS) will record the drone's three-dimensional space coordinates and movement posture information. Affected by airflow and wind direction, the UAV space coordinate information often has vector errors, so it is necessary to perform instantaneous attitude correction on the POS data. In drone tilt photography, we need to know the instantaneous coordinates and instantaneous attitude at the time of aerial exposure, and use the drone's inertial sensor (IMU) three external orientation elements ($\theta, \varphi, \omega$) to correct the POS space latitude and longitude data converted to geocentric coordinate system data $^{[12]}$. The formula is as follows:

$$
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = R_{e}^{m} \begin{bmatrix}
X_p \\
Y_p \\
Z_p
\end{bmatrix} + R_{f}^{e} R_{p}^{f}(\theta, \varphi, \omega) \begin{bmatrix}
X' \\
Y' \\
Z'
\end{bmatrix}
$$

(1)

Among them, $R_{e}^{m}$ is the conversion matrix between the geocentric coordinate system ($e$) and the auxiliary coordinate system ($m$), and $R_{f}^{e}$ is the conversion matrix between the geocentric coordinate...
system \((e)\) and the inertial vector coordinate system \((I)\), \(R_p^l\) is the conversion matrix between the inertial vector coordinate system and the UAV azimuth coordinate system, \(X_p\), \(Y_p\), \(Z_p\) are the UAV azimuth coordinate system coordinates, \(X', Y', Z'\) are eccentric coordinates.

2.2. Using collinear equations to obtain the elevations of topographic feature points

The collinear equation is one of the principle equations in photogrammetry. It represents the mathematical relationship between the eye point, the object image point and the projection center on a straight line \([13]\). In this paper, the eye image point is the UAV's spatial orientation point, and the object image point is the ground terrain feature point. We use the UAV's spatial orientation point and the projection center auxiliary coordinate system to solve the ground feature point coordinates (Figure 2).

As shown in Figure 2, \(\text{POS}(X, Y, Z)\) is the UAV's spatial orientation point, \(I(X_0, Y_0, -f)\) is the projection point of the UAV's spatial orientation point on the projection plane, \(D(x, y, z, y, z)\) are ground feature points, where \(f\) is the focal length of the camera. The relationship between the three is:

\[
\begin{bmatrix}
x - X \\
y - Y \\
z - Z
\end{bmatrix} = \lambda R \begin{bmatrix} X_0 \\ Y_0 \\ -f \end{bmatrix} = \lambda \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} X_0 \\ Y_0 \\ -f \end{bmatrix}
\]

(2)

Among them, \(\lambda\) is the scale factor and \(R\) is the matrix of external orientation elements. According to formula 2, there are:

\[
\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \lambda \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} X_0 \\ Y_0 \\ -f \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}
\]

(3)

The azimuth and elevation of the ground feature points are obtained by formula 3.
2.3. Cluster analysis of feature points
K-means clustering is an unsupervised learning algorithm that continuously changes clustering centers. Its simplicity and fast speed make it widely used in many fields. Perform K-means clustering analysis on the ground feature points obtained by the inversion of the collinear equation. First, normalize the ground feature point data, divide it into n groups, randomly select k cluster centers, and calculate each The distance from the point to the center classifies the ground feature point to the center of its shortest path. Secondly, it is continuously updated according to the center of the point in the class until the dimensionality condition is met. The following is a description of the clustering algorithm:

Algorithm 1 K-means clustering of ground feature points
Require: Ground feature points, the number of center points m, the number of clusters n, the residual Δ
Ensure: cluster (n)
normalization D(n) ← D(x, y, z)
center cluster C(k) ← Random (k)
while (residual > Δ)
    for i in D:
        cluster (n) ← D(i)
    for j in m:
        cluster center ← C(j)
        residual = C(j) - C(j - 1)

2.4. Three-dimensional oblique photography path planning of buildings
Based on the results obtained by K-means clustering, the smallest area of the drone's three-dimensional oblique photography path is divided. The smallest area is constructed by the closed polygon surrounded by the envelopes of the scattered points of the same kind, and the smallest area of the drone's oblique photography path is determined. On the basis of the minimum area, increase the width of the buffer zone to establish the final path area of the UAV oblique photography. The following is the calculation formula of the buffer:

\[ \mu = Z \times \tan \gamma \]

Among them, \( Z \) is the flying height of the drone, and \( \gamma \) is the tilt angle of the photographic lens. According to the UAV route planning area generated by Formula 4, the UAV's course overlap rate is greater than 80%, and the side overlap rate is greater than 70%.

3. Algorithm experiment and result analysis
3.1. Experiment content
In order to verify the reliability of the local UAV oblique photography route planning method, three-dimensional building reconstruction experiments were carried out. DJI Yu air drone was used to perform orthophoto and single-lens five-shot tilt photography on the ground in the experimental area. POS data processing, feature point algorithm, and path planning algorithm were compiled by python3.6, and the 3D reconstruction model of the building was compiled by pix4d Software construction. A total of 270 pictures were obtained for the two sorties. After attitude correction using the orthophoto POS data, the azimuth and elevation data of the ground feature points were obtained. After the feature point data was clustered, the smallest area of the oblique photography path was obtained, and the final result was obtained by increasing the buffer zone. In the path area, a covered route design with a side overlap rate of 70% and a heading overlap rate of 80% is carried out in this area. Import the designed route into the drone for oblique photography. Perform 3D reconstruction on the obtained oblique photographic image,
obtain the 3D model of the building and superimpose the orthographic 2D ground image to obtain the final image.

3.2. Analysis of experimental results

Part of the POS data extracted from the 56 pictures obtained in the first flight is shown in Table 1, and the POS data error value comparison before and after posture correction is shown in Table 2.

| Image number | 66   | 105   |
|--------------|------|-------|
| X/m          | 121.363 | 121.360 |
| Y/m          | 31.05  | 31.04  |
| Z/m          | 35.023 | 35.011 |
| \(\theta\)/% | 3.7    | 3.2    |
| \(\varphi\)/% | 3.1    | 4.0    |
| \(\omega\)/% | 78.3   | 66.1   |

Table 2 Comparison of POS data error values before and after posture correction

| POS data error values | Before posture correction | After posture correction |
|-----------------------|---------------------------|--------------------------|
| \(\Delta X/m\)        | 4.51                      | 1.13                     |
| \(\Delta Y/m\)        | 3.36                      | 1.69                     |
| \(\Delta Z/m\)        | 9.96                      | 3.31                     |
| \(\Delta \theta\)/%   | 3.47                      | 1.51                     |
| \(\Delta \varphi\)/%  | 3.62                      | 3.05                     |
| \(\Delta \omega\)/%   | 5.34                      | 1.99                     |

It can be seen from Table 2 that after the original POS data is posture corrected, the positioning accuracy of the image has been improved. After k-means clustering, the final route area and final route are obtained (Figure 3). According to the course of the oblique photography, oblique photography of the building and three-dimensional reconstruction are performed, and the three-dimensional reconstruction result is shown in Figure 4. From the comparison of the time required for the traditional building 3D reconstruction method and the planned route 3D reconstruction method, it can be seen that although the 3D building reconstruction based on the planned route algorithm in this paper consumes a little more time during the flight phase, it is far ahead of the traditional 3D building reconstruction processing. Reconstruction method (Table 3).
Figure 3 Final route area and final route

Figure 4 Building 3D reconstruction results
Table 3 Comparison between traditional algorithm and the algorithm in this paper

|                      | Traditional algorithm | This algorithm |
|----------------------|-----------------------|----------------|
| Aerial time(h)       | 0.16                  | 0.37           |
| Modeling time(h)     | 5.33                  | 2.08           |

4. Conclusion

In order to meet the requirements for timeliness and process efficiency of the post-earthquake building loss investigation, the UAV tilt photography route planning algorithm proposed in this paper improves the traditional UAV oblique photography route planning algorithm by designing the drone route in the building survey area through cluster analysis on the elevation of ground terrain feature points based on UAV POS data. Furthermore, the above-mentioned algorithm shortened the time required for 3D reconstruction of the building to some extent, and provide technical support for the investigation of building loss after the earthquake. Last but not least, it produces meaningful information for the research of drone route planning for tilt photography.

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