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An absolute orientation realization method based on 3d real scene model

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Abstract. With the development of oblique photogrammetry technology, the 3D real scene models obtained by 3D reconstruction are gradually enriched, and the application requirements for 3D real scene models are becoming more and more extensive, and most of the models often do not have the absolute orientation of the model due to the difficulty of obtaining control points in the field. This type of model cannot be directly used in subsequent measurement and drawing. Therefore, this article combines a small number of field control points to deal with the absolute orientation of the 3D real scene model and adjusts the absolute orientation formula with the aid of the least square method. Experiments prove the feasibility and accuracy of the algorithm in this paper, and provide a feasible absolute orientation method for aerial triangulation and digital mapping of 3D real scene models.

1. Introduction

With the development of tilt photogrammetry, the angle of image acquisition has changed from one to multiple. Simultaneous shooting of one vertical and four oblique angles of the same target feature can obtain rich top and side-view high-resolution textures, which provides technical conditions for constructing a three-dimensional real scene model [1]. Because the acquisition of field control points requires a lot of manpower, the established 3D real scene model cannot be used for measurement without absolute orientation. Therefore, it is urgent to use a few control points to complete the absolute orientation of the 3D real scene model.

In photogrammetry, the orientation of a three-dimensional model is divided into internal orientation and external orientation. The external orientation consists of two processes, relative orientation and absolute orientation [2]. The relative orientation is to restore the relative position of the two beams of the stereo image pair at the time of photography to form a stereo model with any scale in any space similar to reality; absolute orientation is to determine the scale of the stereo model and the prescribed position in the ground coordinate system according to the image control point process.

The relative orientation determines the relative position and posture relationship between the two photos. The coordinates in the model coordinate system are calculated point by point through the space front intersection formula, and a three-dimensional point cloud model similar to the ground is solved. The position of this model is relative and cannot be directly used for measurement. The model must be oriented absolutely to further restore the authenticity of the model. The absolute orientation determines the correct position of the three-dimensional model in the ground measurement coordinate system. With the help of ground orientation points, the three-dimensional model established by the relative orientation is translated, rotated and zoomed so as to be included in the ground measurement coordinate system.

Domestic scholars and Foreign scholars have conducted a lot of research on the method of absolute orientation. Zhang Zuxun [3] proposed an absolute orientation method based on straight line features. Liu



Yanan[4] aimed at the problem that the conventional absolute orientation method needs to arrange enough object orientation points. An absolute orientation method based on directed line segments is proposed, which is used to determine the orientation direction through a vertical line segment and a non-vertical line segment with a known azimuth angle; Zhong Can[5] proposed an absolute orientation method based on plane fitting, which can be used without initial value. Solve the absolute orientation parameters under the circumstances; Dan Rosenholm[6] uses Digital Elevation Models (DEMs) for stereo models and uses slope and elevation information for absolute orientation; Bi Jisheng[7] et al. use Beidou navigation and positioning system to obtain coordinates and combine the least square method. Adjust the absolute orientation formula.

In this paper, the absolute orientation of the 3D real scene model is carried out. In order to meet the needs of different types of aerial images and the number of orientation points, this paper aims to propose an algorithm framework that uses a small number of orientation points and does not depend on the adaptability of the initial position to achieve 3D real scenes. The absolute orientation of the model. In order to achieve the goal, this article first analyzes the feasibility of the algorithm used in absolute orientation, and performs the calculation and adjustment of the absolute orientation formula of the 3D point cloud model. Finally, the feasibility of the algorithm is tested through experiments, and multiple sets of experimental models are used to The method proposed in this paper has been verified.

2. Absolute orientation principle

Absolute orientation is the process of determining the scale of the three-dimensional model and the prescribed position in the ground coordinate system according to the image control points. After relative orientation, a three-dimensional model similar to the ground is established, and the photogrammetric coordinates of each model point have been measured. However, the position of the photogrammetric coordinate system in the geodetic coordinate system is still unknown, and the scale of the model is also approximate. It is necessary to further determine the geodetic coordinates of the model with the help of directional points measured in the field, and perform three-dimensional rotation, translation and zooming of the three-dimensional model. To determine the position and size of the three-dimensional model in the geodetic coordinate system.

The data required for absolute orientation includes the orientation point coordinates of the ground orientation point, the coordinates of the model point in the image space auxiliary coordinate system (ie, the relative orientation result), etc. The problems that need to be solved for absolute orientation include: transforming ground coordinates into ground photogrammetric coordinates and the coordinates of the encrypted points after absolute orientation should be inversely calculated to the ground measurement coordinate system.

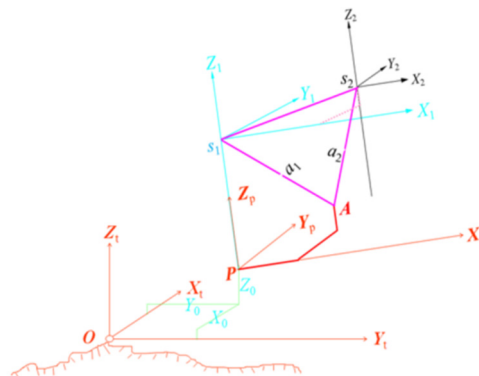


Figure.1 Schematic diagram of absolute orientation

2.1. Formula for the calculation of absolute directional elements

$$\begin{pmatrix} X_T \\ Y_T \\ Z_T \end{pmatrix} = \lambda \cdot M \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} = \lambda \cdot \begin{pmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} \quad (1)$$

X_T, Y_T, Z_T are the coordinates of the ground point in the ground photogrammetric coordinate system. λ is the scaling factor of the model scale. X, Y, Z are the coordinate of the model point in the auxiliary

coordinate system of the image space. $\begin{pmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{pmatrix}$ is the rotation matrix composed of corner element (Φ, Ω, K) . $\Delta X \Delta Y \Delta Z$ are the translation amount of the coordinate origin.

2.2. Traditional absolute orientation process

① The ground measurement coordinates of the directional points used for absolute orientation are converted into the ground auxiliary coordinate. At this time, the angle between the ground auxiliary coordinate and the surveying coordinate system is small, and the scale of the two is also close.

② Determine the initial values of seven absolutely directional elements.

③ Calculate the coordinate center of gravity and the coordinate of the center of gravity.

④ Calculate the center of gravity and center of gravity.

⑤ According to the determined initial value (or new approximation), the constant term of the error equation is calculated.

⑥ The error equation is composed point by point, and the point by point method.

⑦ The correction number of seven absolute directional elements is obtained by solving the equation.

⑧ Calculate the new value of the absolute directional element.

⑨ Determine whether the correction of the absolute directional element is less than the limit. If greater than the limit, repeat (5)~(9).

⑩ According to the absolute directional elements obtained, the measured coordinates of all the model points are transformed into the ground auxiliary coordinate.

The traditional absolute orientation method is often [8] by Euler angle iteration method, which has the [9] of non-convergence, dependence on initial value and calculation time. At present, the absolute orientation method is less used in the 3D point cloud after 3D reconstruction. In this paper, the absolute orientation method is improved and applied to the 3D point cloud model.

2.3. Programming implementation of the absolute orientation approach adopted in this paper

On the principle of absolute orientation, absolute orientation can be regarded as the rigid body change problem of input point cloud and target point cloud after unifying the model scale. The T. of model scale

λ , rotation matrix R and translation matrix should be obtained. And the corresponding points on the point cloud model and the orientation point in the known geodetic coordinate system are P_i and G_i ($i=1/2, \dots, n$). According to the absolute orientation formula, the deformation is:

$$\begin{pmatrix} x_g \\ y_g \\ z_g \end{pmatrix} = \lambda R \begin{pmatrix} x_p \\ y_p \\ z_p \end{pmatrix} + t \quad (2)$$

The key of orientation lies in the solution of rotation matrix. Zhang Yongjun [10] the method of matrix singular value decomposition to obtain the initial value of angular element and the least square adjustment to obtain absolute orientation parameters. Kabsch W [11] Kabsch algorithm is proposed to solve rotation matrix and translate to origin.

This paper intends to use three pairs of directional points to calculate the model scale λ , rotation matrix R and translation matrix T , and solve the relevant parameters by the coordinate relationship of three pairs of corresponding points.

① Acquisition of known orientation points

According to the analysis of absolute orientation elements, absolute orientation requires two flat and high orientation points and another elevation point not on the two-point line. In order to check the accuracy of elevation leveling and facing points, error allocation is carried out to improve orientation accuracy. In this paper, two leveling points and one elevation point solution formula are used to adjust the data with redundant control points.

② Take orientation point coordinates on screen

By selecting the corresponding orientation points on the 3D point cloud model by the characteristics of the orientation points, the point cloud coordinates are selected by the visual function and the registered callback function in the PCL library, which can be obtained by later calculation.

③ For the existing point cloud model, the coordinates of the center of gravity are obtained and the coordinates of the center of gravity are changed.

The purpose of point cloud model coordinate barycenter is to reduce the effective number of bits of model point coordinates in the calculation process to ensure the accuracy of calculation, and to simplify the equation and improve the calculation speed.

Remember that the g_0 and p_0 are the center of gravity of the orientation point in the geodetic coordinate system and the center of gravity of the orientation point of the point cloud model, respectively

$$g_0 = \frac{1}{n} \sum_{i=1}^n g_i \quad (3)$$

$$p_0 = \frac{1}{n} \sum_{i=1}^n p_i \quad (4)$$

Some formula (3) and formula (4) also satisfy $\bar{g}_i = \lambda R p_i + t$, \bar{g}_i and \bar{p}_i are the points after the center of gravity moves to the origin, there are $\bar{g}_i = g_i - g_0$ and $\bar{p}_i = p_i - p_0$.

Then the center of gravity moves to the origin and satisfies the relationship:

$$\begin{pmatrix} \bar{g}_x \\ \bar{g}_y \\ \bar{g}_z \end{pmatrix}_i = \lambda R \begin{pmatrix} \bar{p}_x \\ \bar{p}_y \\ \bar{p}_z \end{pmatrix}_i + t', i \in (1, 2, 3, \dots, n) \quad (5)$$

At this point, according to the known data, we only need to solve the rotation matrix which satisfies the above relation.

④ Computational Model Scale λ

According to the least square method λ the scale coefficient is related to the control point after barycenter and the model point.

The error of each model point can be obtained according to the absolute orientation formula :

$e_i = g_i - \lambda R p_i - t$ to minimize the error, it is necessary to make the $v = \sum_{i=1}^n \|e_i\|^2$ reach the minimum value.

It can be obtained by gravity treatment

$$v = \sum_{i=1}^n \|\bar{g}_i - \lambda R \bar{p}_i - t'\|^2 = \sum_{i=1}^n \|\bar{g}_i - \lambda R \bar{p}_i\|^2 + n \|t'\|^2 \quad (6)$$

According to the least square method, the solution formula of scale λ can be obtained as follows:

$$\lambda = \left(\sum_{i=1}^n \|\bar{g}_i\|^2 / \sum_{i=1}^n \|\bar{p}_i\|^2 \right)^{1/2} \quad (7)$$

Amplification or reduction of the input point cloud model using the λ obtained, after operation, the absolute orientation formula enters the stage of solving the rotation matrix and the translation matrix.

⑤ By singular value decomposition (Singular Value Decomposition, SVD), the rotation matrix is calculated.

Singular value decomposition can represent a more complex matrix by multiplying smaller and simpler submatrices, which describe the important properties of the matrix.

By solving the rotation matrix by corresponding points R the following formula can be rewritten:

$$R = \arg \min_R \sum_{i=1}^n \left\| \bar{q}_i - R \bar{p}_i \right\|_2^2 \quad (8)$$

The matrix $[\bar{g}_1 \bar{g}_2 \dots \bar{g}_n]$ is recorded as X_0 , $[\bar{q}_1 \bar{q}_2 \dots \bar{q}_n]$ is recorded as Y_0 , and the optimization problem is simplified as follows:

$$R = \arg \min_R \sum_{i=1}^n \left\| Y_0 - R X_0 \right\|_F^2 \quad (9)$$

From the SVD principle, the rotation matrix can be decomposed. PCL TransformationEstimationSVD function under the registration class in the library provides a method to calculate the rotation matrix. The change matrix of 4*4 can be obtained by decomposing the singular value.

⑥ Translation matrix through rotation matrix

$$\begin{pmatrix} x_g \\ y_g \\ z_g \end{pmatrix}_i = \lambda R \begin{pmatrix} x_p \\ y_p \\ z_p \end{pmatrix}_i + T$$

The translation vector can be further obtained according to the

$$T = \begin{pmatrix} x_g \\ y_g \\ z_g \end{pmatrix}_i - \lambda R \begin{pmatrix} x_p \\ y_p \\ z_p \end{pmatrix}_i \quad (10)$$

⑦ The least square adjustment of the formula is carried out by the residual orientation point.

In practice, the measurement is imprecise, so more than three points are used to seek greater accuracy in determining the transformation parameters, and a more accurate value is obtained by the least square method.

A least square adjustment (least squares method) mathematical optimization technique is to find the best function match of the data by minimizing the sum of the squares of the error. The unknown data can be easily obtained by using the least square method. The sum of squares of errors between the obtained data and the actual data is minimized.

According to the $e_i = g_i - \lambda R p_i - t$, the least square adjustment is carried out.

⑧ If the error is greater than the limit, the third step to the seventh step are recalculated until the error satisfies the condition, the iteration is stopped, and the absolute orientation formula of the final 3D point cloud model is obtained.

3. Implementation of Absolute Orientation of 3 Point Cloud Model

In order to verify the effectiveness of the improved algorithm, the experimental verification is carried out in this paper. The experimental platform is processor Intel (R) Core (TM) i78750H CPU @2.20GHz 2.21GH, memory 32.0 GB 、64 bits. Mobile graphics and image workstation in Windows10 environment

of operating system with GeForce RTX2070.GPU of workstation Absolute orientation needs to realize the transformation of ground orientation point from image space auxiliary coordinate to photogrammetry ground coordinate.

The flow chart adopted in this paper is as follows:

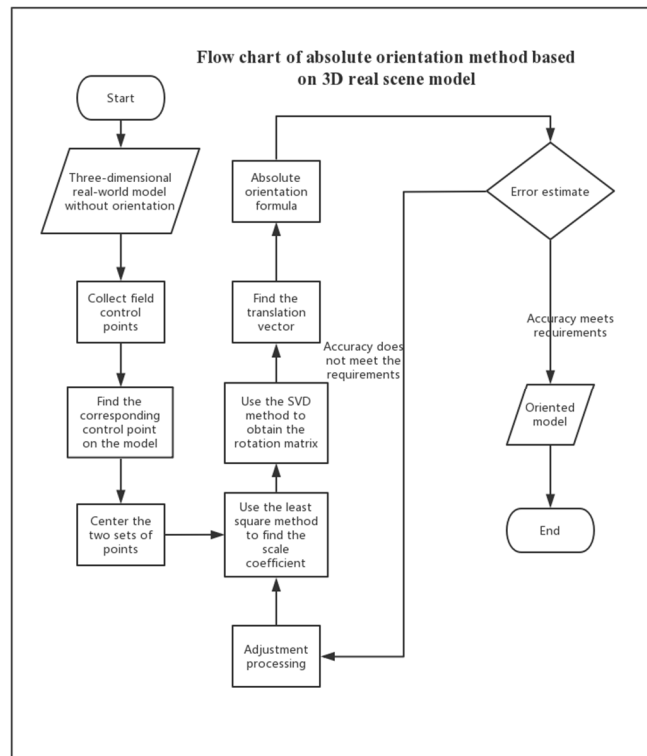


Figure.2 The algorithm flow chart of this paper

Absolute orientation is a prerequisite for 3D point cloud models reconstructed by tilt photogrammetry to be put into measurement and subsequent data analysis. Absolute orientation accuracy affects the accuracy of the final product. Referring to the requirements of the specifications for aerial triangulation of digital aerial photogrammetry[13] with the specifications for aerial photogrammetry of topographic maps 1:500, 1:1000 and 1:2000[14], For a 1:1000 topographic map, Absolute directional plane-to-point error, Flat, hilly areas generally not greater than 0.4 mm, above Maximum not greater than 0.5 mm; High mountain areas generally not greater than 0.5 mm, Maximum not greater than 0.6 mm. the elevation orientation error is not greater than the elevation median error of the encrypted point; When the flat land, hilly land, Elevation error not greater than 0.3mm.

The precision of absolute orientation affects the precision guarantee of the final product, so every step should be carefully operated and controlled. In order to test the accuracy of the algorithm, many experimental adjustment calculations are carried out. Two sets of data show that the absolute orientation algorithm in this paper is feasible and the speed of solution is relatively fast.

First, we use the remote sensing image of Xi'an Dayan Pagoda of UAV to test the function of the algorithm. The data are collected by Google Earth to obtain the longitude, latitude and altitude data of the orientation points around the Big Wild Goose Pagoda. The corresponding point cloud XYZ data are taken on the 3D real scene model. The experiment is carried on in the Visual Studio 2017 environment, with the PCL library 1.9.1 as the support platform, carries on the screen orientation point coordinate extraction.

Compared with the three-dimensional real scene model of Google Earth and Big Wild Goose Pagoda, the corner points easily identified in the building are selected to select the corresponding orientation points.

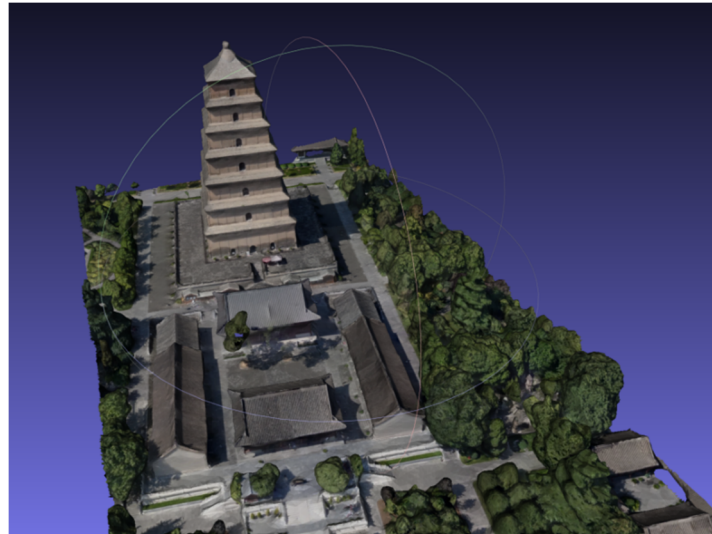


Figure.3 Schematic diagram of the three-dimensional reconstruction model of the UAV image of the Big Wild Goose Pagoda in Xi'an

Table.1 The coordinates of the corresponding points of the model and the coordinates of the control points selected on Google Earth

	P1	P2	P3	Q1	Q2	Q3
x	369.978	310.094	398.008	34°13'11.34" N	34°13'8.78" N	34°13'8.81" N
y	454.107	309.073	300.519	108°57'33.66" E	108°57'32.70 E	108°57'34.69" E
z	-104.869	-210.632	-206.19	498 m	443 m	443 m

Bring P and Q into the settlement procedure of absolute orientation, and compare the coordinate errors after absolute orientation:

Table.2 Absolute directional element calculation

λ	R	T
1.26131	$\begin{pmatrix} -0.00563387 & 0.661816 & 0.749645 \\ 0.994803 & -0.0725048 & 0.0714864 \\ 0.101664 & 0.746152 & -0.657968 \end{pmatrix}$	$\begin{pmatrix} 3.80611e+06 \\ 4.93717e+07 \\ -62.7591 \end{pmatrix}$

Then get the orientation error as shown in the following table:

Table.3 Absolute orientation error

Error	P1	P2	P3	Distance mean square error
ΔX	-0.425	0.125	0.3	
ΔY	-0.4	-1.2	0.4	
ΔZ	-1.08908	0.312714	0.776398	1.144978769
$\sqrt{\Delta X^2 + \Delta Y^2}$	0.583630876	1.206492851	0.5	
Point offset	2.330874711	2.413098305	0.727257358	

The experimental results show that the method used in this paper is feasible for the absolute orientation of the point cloud model, because the model is small. The accuracy of the algorithm will be affected by the error of selecting the corresponding points on the model and the deviation of the control points on Google Earth.

The second set of test data uses a AMC580 camera to obtain a 3D real scene model with a resolution of 10 CM in a certain area of Dengfeng City. The focal length of the lower view camera is 55 MM, and the focal length of the tilt camera in four directions is 80 MM, the navigation overlap rate is 80 and the

side overlap rate is 60. The absolute orientation method of the 3D real scene model obtained by relative orientation is tested.

The three-dimensional reconstruction is shown below:

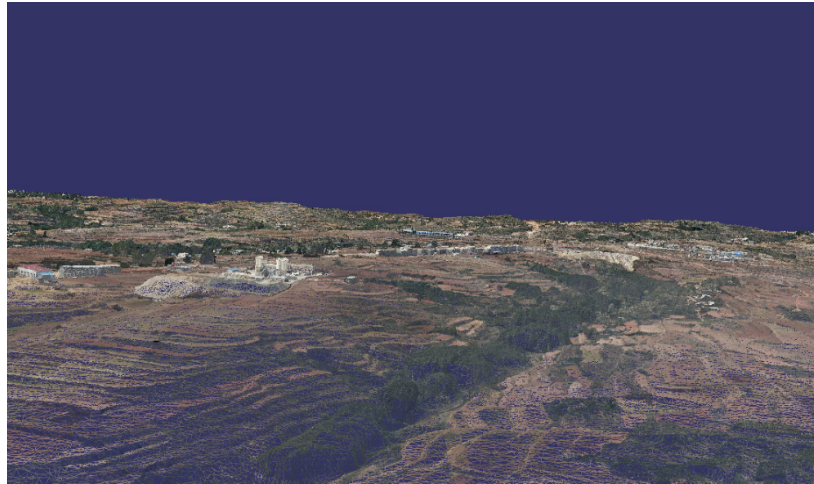


Figure.4 Map of 3D Reconstruction Model of UAV Image in Dengfeng City

Table.4 The Error of Out-of-field Control Point and the Algorithm in this paper

	X	Y	Z	ΔX	ΔY	$\sqrt{\Delta X^2 + \Delta Y^2}$	ΔZ
P1	2891.28	531.023	360.952	0.076404	-0.08287	0.112716494	0.3036
P2	2954.7	2616.15	359.76	0.082441	-0.0324	0.088579221	0.0448
P3	1837.03	1666.56	400.035	-0.07307	0.050022	0.088551823	-0.0299
P4	1895.01	2504.42	373.887	-0.07794	-0.06961	0.10449974	0.0451
P5	1039.69	645.099	333.404	0.0722	-0.05337	0.089784168	-0.0807
P6	960.645	2491.84	324.965	0.043761	0.05273	0.068523558	0.0503
P7	-866.832	1370.26	392.91	-0.00333	-0.04244	0.042570442	-0.0417
P8	-985.871	2379.56	290.787	0.027254	0.061748	0.067495156	0.0117
P9	-2012.47	735.256	375.492	-0.05053	0.041731	0.065534398	0.0452
P10	-2096.42	2461.44	299.94	0.076061	-0.05929	0.096439514	0.0221

According to the data obtained from experiment 2, the accuracy of the algorithm is reliable and meets the requirements of mapping.

4. Innovation points of this paper

① This article uses tilt photogrammetry technology to obtain a three-dimensional real-world model after three-dimensional reconstruction for experimental testing. The three-dimensional real-world model is automatically constructed by a computer to restore the complete appearance of the real world, covering all elements of the environment (except mirrors, water surfaces, Wind and other things that the camera cannot capture). The 3D real scene model has more complex environmental

elements. After the absolute orientation of the 3D real scene model is carried out, the model can be directly used for subsequent map drawing, map measurement and other applications.

② Use fewer directional points for measurement, reducing the workload of field directional points acquisition. The experimental data has no dependence on the initial value and can be adapted to absolute orientation in various situations.

③ According to the accuracy requirements of map mapping, the error evaluation of the experimental data is carried out, which conforms to the national digital mapping standard, and has a wider practical application value for future smart cities, emergency command response, and city management.

5. Summary

The absolute orientation method described in this article provides a precise and reliable absolute orientation method for many applications. The algorithm performs absolute orientation on the three-dimensional real scene model obtained by three-dimensional reconstruction of photogrammetry. By selecting control points and corresponding points of the model, the scale coefficient is obtained by the least square method and the rotation matrix is obtained by singular value decomposition, and the absolute orientation formula is calculated, and finally use the least square method to deal with the formula error. Experiments have proved the feasibility and accuracy of the method used in this paper. This method avoids iterative calculations, has a fast running time, can effectively improve the accuracy of absolute orientation, and has relatively low requirements for the number of absolute orientation points.

The stereo pair orientation is the prerequisite for the entire stereo data collection and the key to the accuracy of the final product. The control error is to ensure the accuracy of mapping and the reliability of subsequent map product data. It is feasible to use the algorithm in this paper to analyze the absolute orientation of ground photogrammetry, and the matrix analysis based on singular value decomposition has high accuracy. Directly calculate the orientation parameter solution, the solution accuracy is relatively high, and the calculation can save a lot of time; when the rotation angle and When the zoom factor is large, the usual orientation method is used, which requires a good initial value, but the algorithm in this paper has no requirement on the initial value and is suitable for most models. Although the accuracy of the model orientation is considerable, in the follow-up work, the formula derived in this paper will be further used to carry out the independent model method regional network adjustment, which is very meaningful for the improvement of calculation speed and the elimination of gross errors.

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