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Research on TIN Curved Surface Modeling Technology and Its Application in Foundation Pit Monitoring

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Abstract: *In Order to Study the Foundation Pit Surface Deformation Amount and its Three-Dimensional Visualization, The Surface Modeling Technique Based on the Grid-Type Discrete Point Cloud Data and Tin Data Model is proposed. Indoor Tests Show that the Minimum Value of the Maximum Residual Value of this Technology is 0.5612~0.9993, Which Meets the Requirements of the Software Spatial Coordinate Solution and Three-Dimensional Reconstruction. And Monitoring the Application Test, the Actual Value and Calculation Value Error is Less Than 1mm, Accuracy and Error Meet the Requirements of the Engineering Measurement Specifications. Finally, the Feasibility of the Technology is Verified by the Field Test.*

Keywords: *Three Dimensional Reconstruction, Tin; Grid Data, Point Cloud Data, Residue*

Surface modeling technology can be summarized as three surface modeling techniques [1-7]: (1) surface modeling technology based on NURBS surface; (2) surface modeling technology based on triangular surface; and (3) reconstruct surface objects in a polyhedral manner. Irregular triangular networks (TIN-Triangulated Irregular Network) is a technique for surface modeling using a series of non-overlapping connected triangular surfaces.

The advantage of the TIN model is that it can describe the surface with different levels of resolution. Compared with the grid data model, the TIN model can represent more complex surfaces with less space and time at a specific resolution, especially when the terrain contains a large number of features such as fracture lines, structural lines, the TIN model can better consider these characteristics and more accurately and reasonably express the surface form, so the triangular network model has the characteristics of high precision, fast speed, high efficiency and easy to handle fracture lines and ground.

Throughout the development of deformation monitoring technology in the past 10 years, the traditional surface deformation monitoring method mainly adopts geodetic method and near-field photogrammetry method [8].Although GPS technology and 3 D laser scanning technology have developed rapidly in the deformation monitoring, due to its various limitations, the engineering slope deformation monitoring has not been widely used. Digital near-field photogrammetry is a contactless measurement method and its data is very fast, high accuracy and easy to store. However, the key to 3-dimensional near-field photogrammetry is in the point cloud data surface modeling based on grid type. It can not only quickly reconstruct the 3 D surface, but also obtain the spatial coordinates of the point cloud through the target, so as to obtain the dynamic change and deformation amount of the surface.

Table 1 Monitoring method comparison and analysis table

Monitoring method	Accuracy	Operational nature	Economy
Full station instrument, precision level instrument	The accuracy is high, and the accuracy of 2~5mm + 2ppm, level is 0.01mm	Simple to operate, but with high labor intensity	Low price
GPS, RS	High accuracy, the signal is susceptible to interference	Simple operation, intelligent, high efficiency	High price
Traditional near-view photogrammetry techniques	Accuracy meets the general requirements	External data collection is simple, but the 3 D reconstruction of the internal industry	Low in cost

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1. Scatter Unconstrained Tin Surface Modeling Principle

TIN is a typical vector data structure that displays or implicitly expresses the topological relationship of the terrain scatter by the relationship between nodes, triangular edges, and triangular faces, requiring efficient TIN storage and organizational structure. Triangle division criterion of the TIN: The geometry of the triangle in the TIN model directly determines the application quality of the TIN. Considering the terrain anisotropy and spatial self-correlation, and practice proved that the interpolation accuracy of long and narrow triangle is lower than the regular triangle credibility; the triangle in TIN is required as close as possible positive triangle, nearest neighbor points connected to triangle, triangle unique. Triangulation algorithm and program: the first two must have an efficient triangulation algorithm and program to implement.

2. Mathematical Principle of Spatial Coordinate Solution

Non-contact digital near-field photogrammetry technology is to calculate the spatial three-dimensional coordinates of the target point on the basis of the image information of the target point and the relevant parameters of the digital camera, using the optical principle and the spatially known target. Assuming a certain point of $p(x, y, z)$ in the space, whose projection points on the two photos are $P'(x_1, y_1)$ and$P''(x_2, y_2)$, respectively. The camera taking the photo is located in the projection center $S(X_s, Y_s, Z_s)$and the three angles between the coordinate system and the p point are ω, φ, k, and the focal length of the camera is f.

It is that the P, P'(or P'') and S three points are in a straight line and, depending on the collinear equation, the relationship between the three can be expressed by the following formula.

$$x_i = -f \cdot \frac{r_{11}(X-X_S)+r_{12}(Y-Y_S)+r_{13}(Z-Z_S)}{r_{31}(X-X_S)+r_{32}(Y-Y_S)+r_{33}(Z-Z_S)} \quad (1)$$

$$y_i = -f \cdot \frac{r_{21}(X-X_S)+r_{22}(Y-Y_S)+r_{23}(Z-Z_S)}{r_{31}(X-X_S)+r_{32}(Y-Y_S)+r_{33}(Z-Z_S)} \quad (2)$$

In the formula $i = 1, 2$, r_{ij} can be represented by the following relation, that is:

$$R(\omega_i, \varphi_i, k_i) = R(\omega_i)R(\varphi_i)R(k_i) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \quad (3)$$

and

$$R(\omega_i) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega_i & \sin\omega_i \\ 0 & -\sin\omega_i & \cos\omega_i \end{bmatrix}$$

$$R(\varphi_i) = \begin{bmatrix} \cos\varphi_i & 0 & -\sin\varphi_i \\ 0 & 1 & 0 \\ \sin\varphi_i & 0 & \cos\varphi_i \end{bmatrix}$$

$$R(k_i) = \begin{bmatrix} \cos k_i & \sin k_i & 0 \\ -\sin k_i & \cos k_i & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Of course, the three-dimensional coordinates of the space point cannot be determined based on the spatial point P alone, and in order to further solve them, another set of relations needs to be established. It can be found from the figure that P is in the same plane as two camera points S' and S'' in two different locations, so you can establish a coplanar equation of the three, i. e.:

$$F = \begin{vmatrix} b_x & b_y & b_z \\ u_1 & v_1 & w_1 \\ u_2 & v_2 & w_2 \end{vmatrix} = 0 \quad (4)$$

Among them

$$\begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} = \begin{bmatrix} 1 & -k_i & -\varphi_i \\ k_i & 1 & -\omega_i \\ \varphi_i & \omega_i & 1 \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ -f \end{bmatrix} i = 1, 2$$

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In the formula, $\begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix}$ is the vector size between points S' and S''

3. Indoor Test

3.1 Camera Calibration

Before monitoring using near-field photogrammetry, the camera used during filming should be calibrated. The purpose of camera calibration is to allow the software to identify parameters of the camera including focal length, coefficient of variation and optical parameters while storing these parameters in the software in the form of a data file. When taking photos using the labeled camera, these photos also contain the parameters and the dynamic parameters of the cameras. When the operator imports these information photos containing the marked points into the image analysis software, the software recognizes these parameters, and then identifies the camera parameters in the corresponding database, summarize all these parameters and then reverse the coordinates. If the camera is used without calibration, the software recognizes the photos with the wrong prompt, so that the subsequent analysis cannot be done, so the calibration of the camera is very important.

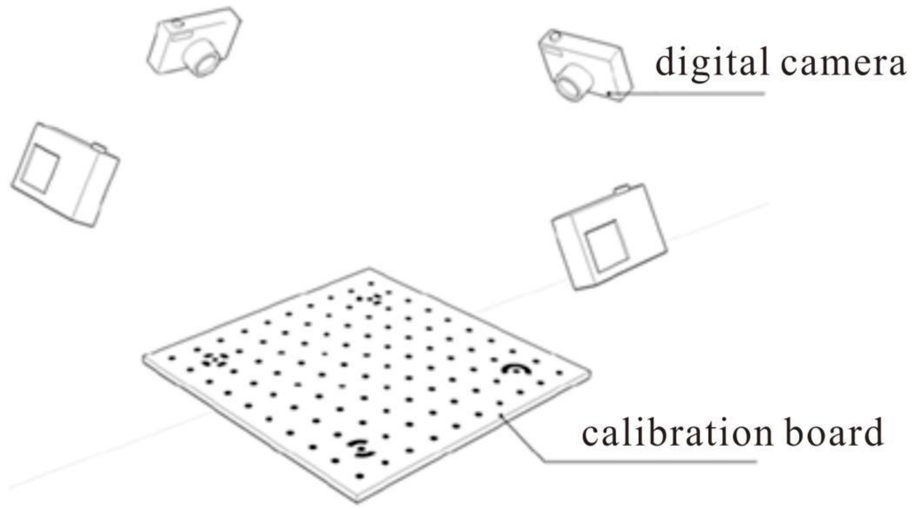

Figure 1 The camera's calibration

As shown in FIG. 1, the calibration board is the object the camera requires during the camera calibration. On the calibrated board, the equal distance distribution has 100 marker points, each distance of 70mm, for the entire calibration plate size of 630cm×630cm.There are also 4 large control points in these marking points, with the inner diameter consistent with other ordinary marking points, all with a 9mm, outer diameter of 38mm.The shapes of the four control points are different from each other. Before the calibration shooting of the camera, in this paper, we mainly calibrates the multiple focal range of FZ35 and Eos 7D cameras.

During the shooting, the camera was first placed and the calibration board was shot in four directions at 90° intervals between each direction. Each picture needs to include all the marks on the calibration board, and they need to occupy more than 70% of the picture area. The camera is then rotated 90° to the right, and finally the camera 90° to the left for the last set of photographs, hence the total of twelve photographs required to be taken for each focal length during the calibration of the camera. After the software analysis of the calibration results at different focal lengths are obtained.

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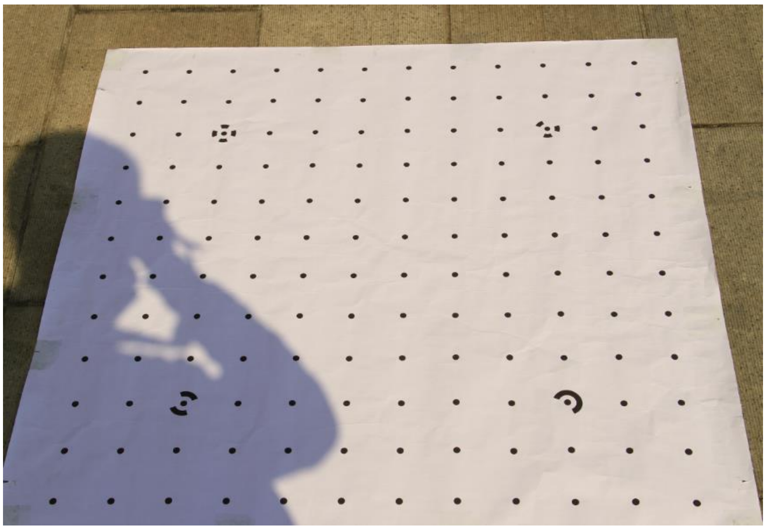

Figure 2 Calibration board

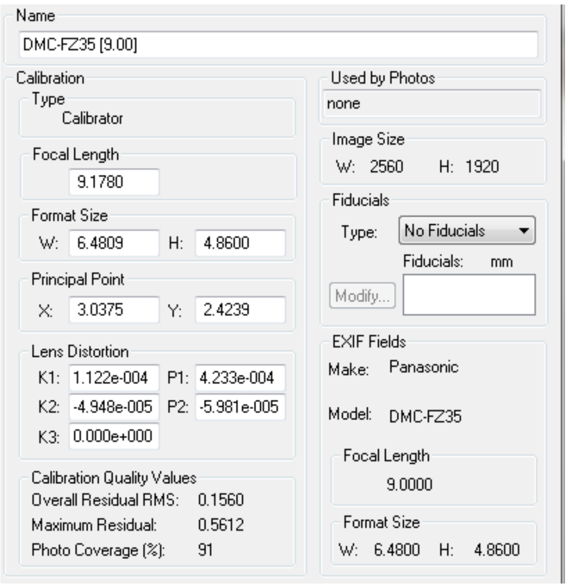

Figure 3 FZ35 [9.00] calibration results

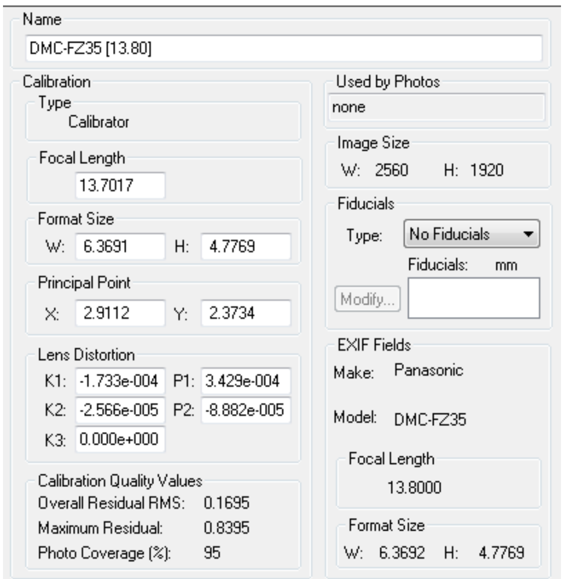

Figure 4 FZ35 [13.80] calibration results

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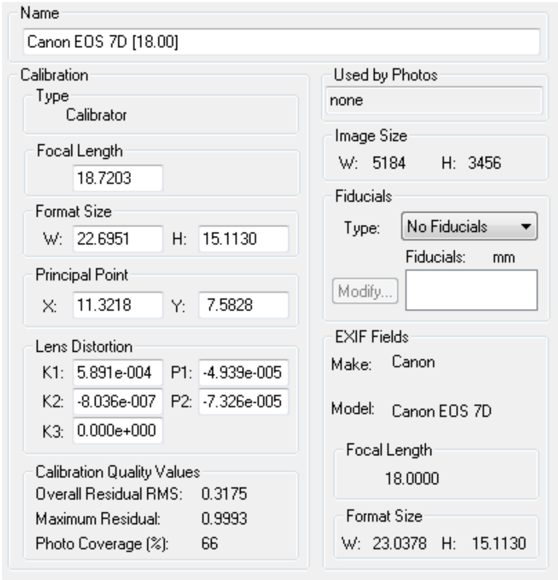

Figure 5 The Eos 7D [18.00] calibration results

From the calibration results of Fig. 2-5, the minimum residual value of the maximum value is 0.56(FZ35[9.00mm]), according to the recommendation of PMS software, the maximum residual amount should not exceed 1, so the smaller the value indicates the higher the calibration accuracy. Since the Canon Eos7D adopts the 18-135mm zoom lens, the focal distance is easy to control, and the camera response time is short. According to the requirements of the maximum residual value, the calibration result of 18mm is adopted, and the focal distance is used for image acquisition in indoor and outdoor tests.

3.2 Model Test

After the camera is verified, the camera (two types of cameras for indoor calibration, namely, card machine and SLR camera) is tested for the indoor model. The indoor model is shown in Fig. 6, a total of nine identification points of the same size, the identification point cover is blackened, and a white dot in the center of the identification point cover. The nine identification points are arranged at a mutual distance of longitudinal 25cm, transverse 15cm, and the far right is 12.5cm and 15cm.And the nine points are exactly the same coordinates in the vertical direction. After arranging this model, photographing it with a verified camera (F=18mm), taking eight pieces from all sides of the model, and then analyzing the standard module in the PMS software to obtain data from the nine points.

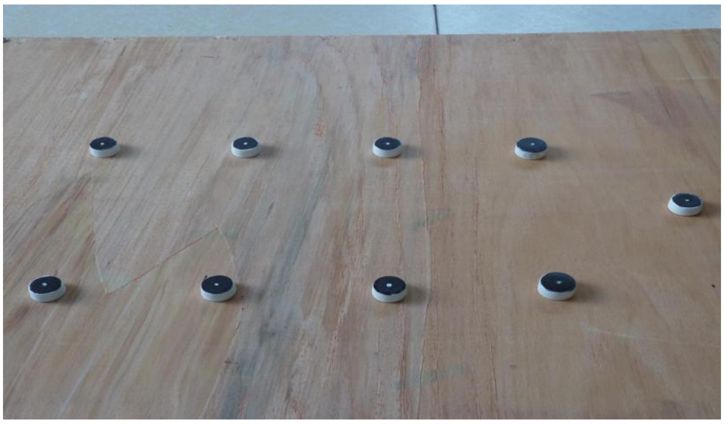

Figure 6 Arrangement of the identification points

As shown in the Fig 7 below, there are three folding lines that represent the difference fluctuation range between X, Y, Z and actual coordinate values of the nine points respectively. So the maximum error of no more than 1mm, fully meets the accuracy requirements of slope monitoring.

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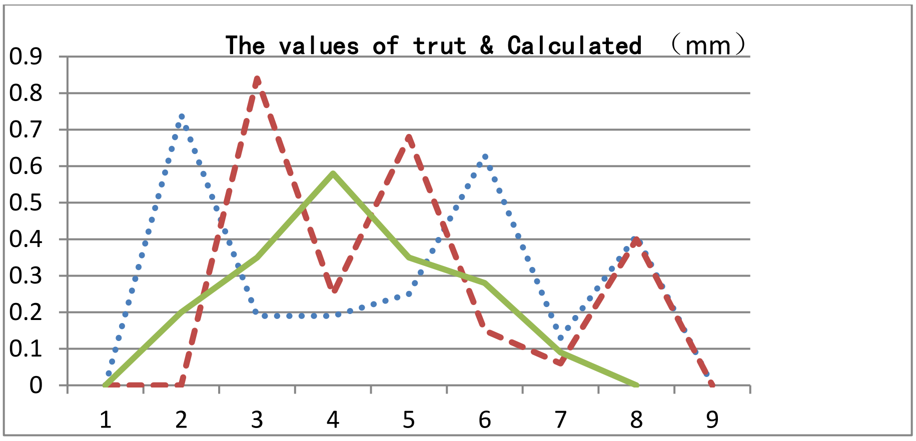

Figure 7 The values of trut & Calculated

4. Outdoor Test

After completing the indoor test, the researchers carried out field monitoring of a slope in Changsha to obtain the grid point cloud data of the slope, and generate a three-dimensional scanning model and cloud map of the slope. The test results are shown in Figure 8-11.

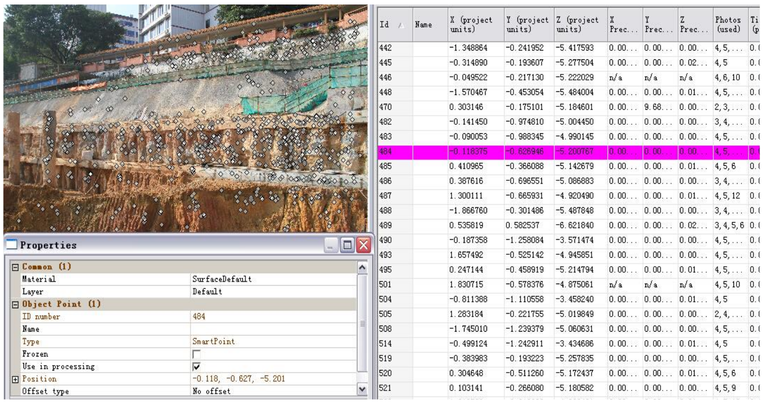

Figure 8 Discrete point cloud data of a foundation pit in a commercial center

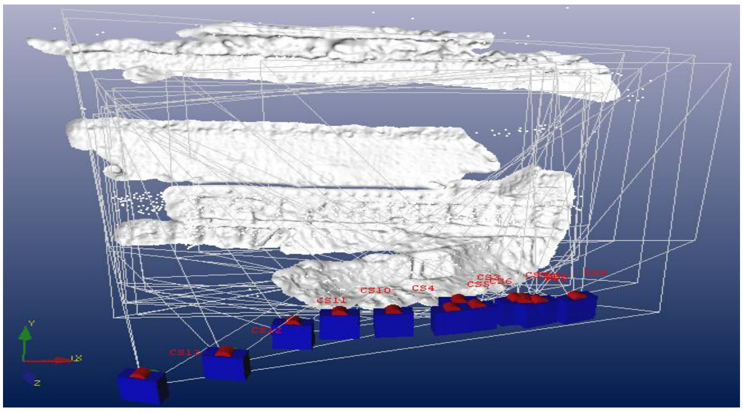

Figure 9 3 D reconstruction of the-point cloud data

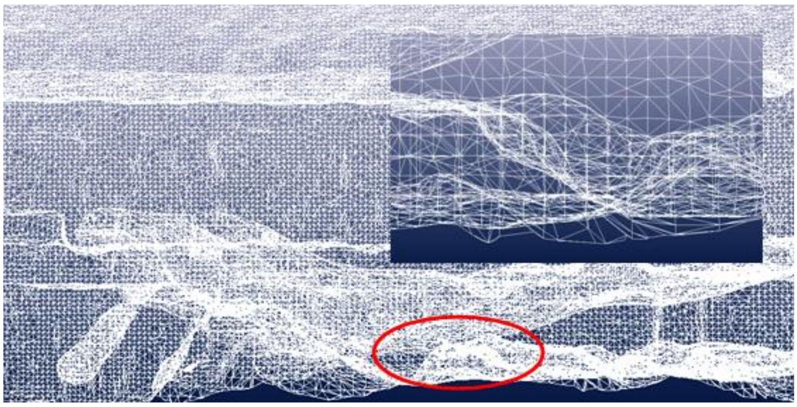

Figure 10 The TIN surface model of the foundation pit surface

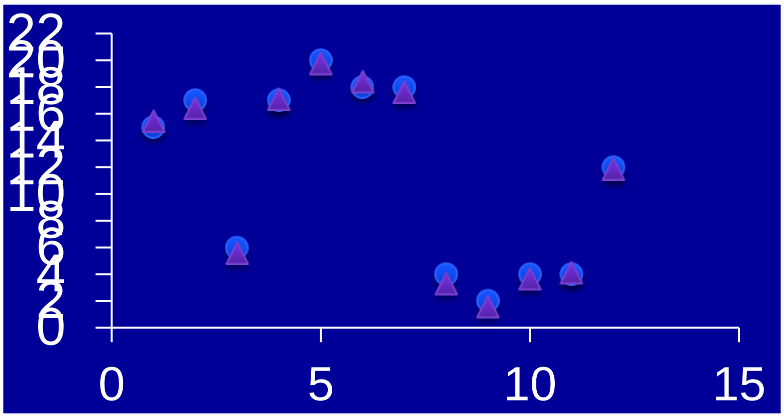

Figure 11 Monitoring Data Comparison

Through engineering application examples, TIN surface modeling technology and near-field photogrammetry technology application and foundation pit monitoring, the actual error compared with the third-party monitoring data, the maximum error is not more than 5%, to meet the engineering error and accuracy requirements, and its speed, high work efficiency, all-weather real-time characteristics bring a wide prospect for its wide application.

5. Conclusion

Through indoor test of TIN surface modeling technology, the maximum value of maximum residual is 0.56, the error is less than 1mm, accuracy and error meet the engineering measurement requirements, and the feasibility of engineering slope deformation monitoring of the technology is verified by site test.

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