# Application of phase three dimensional laser scanner in high altitude large volume irregular structure

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ABSTRACT: The precise measurement and positioning of the outline of high-altitude massive special-shaped structure has a guiding role in the installation of its external curtain wall and other ancillary facilities. Traditionally, total station measurement and other technical methods are mostly used, which have the disadvantages of large workload, long time-consuming and low accuracy. This paper takes the high-altitude corridor enclosure structure of Chongqing Raffles Square as the research object, combines the characteristics of Leica Nova MS60 high-precision three-dimensional laser scanning total station which can accurately locate and Faro x330 three-dimensional laser scanner which can scan quickly, and puts forward an excellent combination of two instruments. Based on the point scanning method and the mathematical optimization theory, a high-precision registration formula for point clouds with special-shaped structures is derived. On the premise of meeting the registration accuracy of point clouds, the rapid scanning and global positioning of a large number of special-shaped components are realized, and precise data are provided for the rapid extraction of contours. It has great application prospects and important applications in reverse modeling and deviation analysis.

## 1. INTRODUCTION

The super-high-rise air corridor is a new type of complex steel structure, which brings great difficulties to the field construction because of its unique structure and complex force characteristics. Taking chongqing Raffles high-altitude view flyover as an example, in order to obtain the true line shape of the enclosure structure and provide the basis for the curtain wall installation, the traditional method uses the total station to carry out single point measurement, and the line of the measured points is connected to obtain the line shape of the enclosure structure.

Now 3D laser scanning technology is introduced, but the data obtained by the ground 3D laser scanner are in the local coordinate system centered on the station, and the data obtained by different stations need to be unified into the global coordinate system. Chen et.al(2014) used a total station to measure the geodesic coordinates of the target, and transformed the data obtained by the scanner through the coordinate system of the target. However, the method is not efficient and the accuracy of the global coordinate system is limited. Zhu et.al(2018) measured the control point as the scanner erection point through the total station instrument. The selection requirements are high, and it is necessary to ensure that there are overlapping parts of the scanning area of the adjacent stations, and the scanning sites are not flexible enough.

In view of the above problems, this paper proposes a new method of combining Leica NovaMS60 high-precision 3D laser scanning total station with Faro x330 3D laser scanner, which gives full play to the advantages of Leica's high-precision global coordinate system positioning total station instrument, and has the function of measuring points of global coordinate system with certain scanning density.

## 2. NEW METHOD FOR SCANNING HIGH-ALTITUDE LARGE-VOLUME HETEROSEXUAL STRUCTURES

In order to solve the problems of time consuming, difficulty and low precision, this paper proposes a new data acquisition method, combining with the characteristics of two methods of collecting data, a mathematical optimization theory is proposed to derive the point cloud high precision registration formula, which realizes the high efficiency, omnidirectional and high precision data acquisition and processing of large volume complex structures.

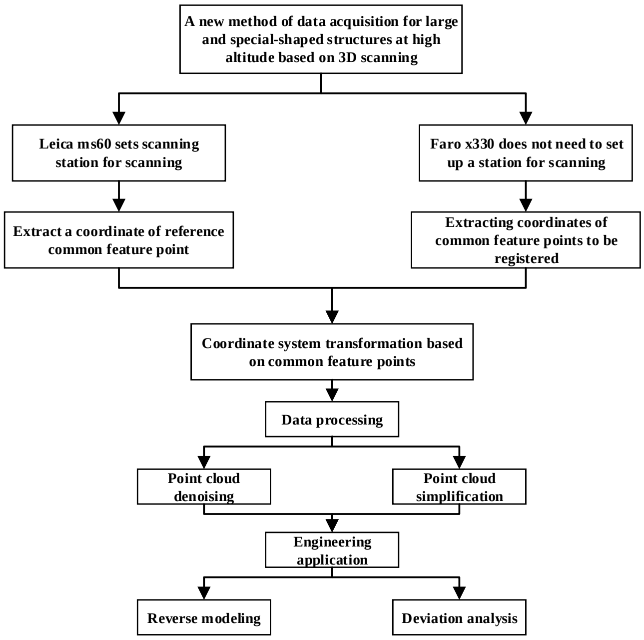


Figure 1. Technical route

## 2.1 *Data acquisition and processing*

### 2.1.1 *Scanning scheme*

According to the coordinates of the two known control points, Leica uses the rear intersection mode to set up the station. The accuracy of the scanning data is controlled at the horizontal interval of 3 mm and the vertical interval of 5 mm, so as to obtain the more dense point cloud data. In order to ensure the accuracy of the later point cloud splicing, faro uses the same site, the same precision way to obtain the point cloud data, and Leica is erected in the same position, which ensures that the collected scanning data is in the same side, the same position, the same distance, and the same scanning accuracy is set by faro scanner to ensure that the two periods of data are scanned at the same accuracy.

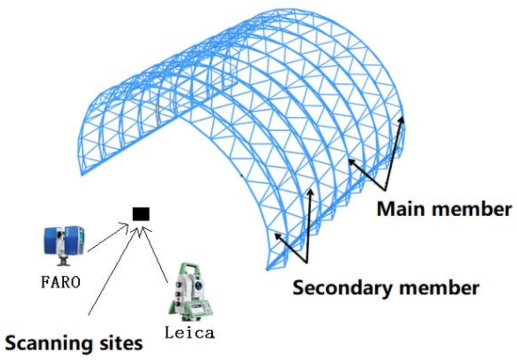


Figure 2. Scanning scheme and site layout

### 2.1.2 *Data denoising and streamlining*

In this paper, the gaussian filter method is used to denoise the original data(Liang.2019). Gaussian filter method uses the gaussian function to still maintain its characteristics after passing Fourier transform, and locates the designated area weight gaussian distribution to achieve the effect of noise reduction. Although the point cloud after denoising reduces the interference of miscellaneous points, the amount of data is still massive, so it is necessary to streamline and compress the data(Li,et.al.2019; Wan,et.al.2016;Peng,et.al.2013;Siddiqui, et.al.2007). In this paper, by sampling by curvature, the data is reduced without affecting the surface reconstruction and ensuring certain precision, thus improving the speed of data processing.

## 2.2 *Point Cloud Registration*

Since the point cloud data obtained by Faro scanner is based on the local coordinate system, and Leica is set up by station, the scanned data is based on the field construction coordinate system, so there is a coordinate conversion problem between the two. Using the seven-parameter registration principle based on the common feature points (Xie,et.al.2017), at least three pairs of common feature points are obtained in the common part of the point cloud in two phases respectively. The maximum deviation is minimized by iterative optimization of the algorithm, thus the conversion parameters are calculated and the point cloud coordinate system is transformed.

Each selected two-stage point cloud corresponds to three pairs of common feature points. Two-piece point clouds are accurately registered by the algorithm optimization principle(Koguciuk,2017; Quan,et.al.2019), where the matrix a represents the faro scan data feature point coordinate information and the matrix b represents the Leica scan data feature point coordinate information.

The point cloud registration rotation matrix is:

$$R_\alpha = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$R_\beta = \begin{bmatrix} \cos(\beta) & 0 & \sin(\beta) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\beta) & 0 & \cos(\beta) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$R_\gamma = \begin{bmatrix} \cos(\gamma) & \sin(\gamma) & 0 & 0 \\ -\sin(\gamma) & \cos(\gamma) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Translation matrix:

$$T_{xyz} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ x & y & z & 1 \end{bmatrix} \quad (4)$$

where $\alpha,\beta,\gamma$,are the rotation angles around the x, y, and z axes, and x, y, and z are the translational distances along the x, y, and z axes.

Post-registration location information:

$$A' = R_\alpha \cdot R_\beta \cdot R_\gamma \cdot T_{XYZ} \cdot A \quad (5)$$

Registration Deviation:

$$D = B - A' = \begin{bmatrix} \Delta x_1 & \Delta y_1 & \Delta z_1 \\ \Delta x_2 & \Delta y_2 & \Delta z_2 \\ \Delta x_3 & \Delta y_3 & \Delta z_3 \end{bmatrix} \quad (6)$$

The results show that the best registration results can be obtained by using the maximum deviation minimization as the objective function.

The objective function is as follows :

$$f(\alpha,\beta,\gamma,x,y,z) = \min\left\{\max_{i=1,2,3}\left[\sqrt{(\Delta x_i)^2+(\Delta y_i)^2+(\Delta z_i)^2}\right]\right\} \quad (7)$$

## 2.3 *Analysis of splicing accuracy*

To test whether the stitching accuracy meets the requirements, it is now verified from the following three aspects:(1) calculating whether the distance determination error between each pair of feature points meets the requirements; and (2) fitting the common part of the circular pipe point cloud to determine whether the diameter of the circular pipe meets the design requirements.

### 2.3.1 *Analysis of stitching accuracy between corresponding feature points*

By calculating the distance between each pair of feature points to determine whether the error meets the requirements.

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \quad (8)$$

### 2.3.2 *Comparative analysis of pipe diameter*

The point cloud of the same part of Leica and faro scan is fitted respectively, then the diameter of the point cloud of the same part after registration is obtained, and the diameter of the point cloud fitting after registration is compared with the expected value.

Registration error assessment function:

$$W = E - E_P ; \quad (9)$$

$$E = (R_l + R_f)/2 ; \quad (10)$$

W: registration bias;

$R_l$: Leica scan point cloud fitting tube diameter value;

$R_f$: faro scan point cloud fitting tube diameter value;

E： Leica and faro scan point cloud fitted the desired value of the cylinder;

$R_P$: after registration point cloud fitting tube diameter value;

# 3. PROJECT CASES

## 3.1 *Engineering Profile*

Chongqing Raffles "Crystal Corridor" is the first high-altitude view flyover over 200 meters in China, with a total length of about 300 meters and a width of about 30 meters. The cross section of the enclosure structure is arched with a height of about 16 m and a span of 31 m. By the transverse span of the main bar and the longitudinal secondary bar welding composition, all the members of the pipe. The exterior of the enclosure structure is covered with glass curtain wall, so the installation and positioning of the curtain wall should be based on the shape of the enclosure structure. However, the construction of the enclosure structure is complex, and its installation process is the splicing of the upper part of the main structure of the corridor after the ground welding of the local bar, the weight of the bar is affected during the lifting process, and the assembly in the field installation process.Due to the influence of the connection error, the bar has been deformed, so there is a big deviation between the theoretical line and the actual line, which cannot truly reflect the contour and line shape of the enclosure structure, so it is difficult to guide the installation of the external curtain wall accurately.

## 3.2 *Instrument introduction and comparative analysis*

The instruments used in the accurate scanning of the enclosure structure of the air corridor in Leica Nova MS60 are phase scanners, which are Leica Nova MS60 high-precision 3D laser scanning total station and Farox330 3D laser scanner. Leica MS60 high-precision 3D laser scanning total station has the functions of total station and scanner, but it is time-consuming. The scanning rate of the instrument can reach 976000 points per second, and the field of vision is wide, but its point cloud data is based on the local coordinate system, so it is difficult to compare with the components in the field construction coordinate system, so there is the problem of coordinate system transformation.

In view of the shortcomings of each of the above two kinds of instruments in the scanning process, a new scanning method is introduced, which combines the characteristics of Leica Nova MS60 and Farox330 fast scanning, and two kinds of instruments are used to scan the same component under the condition of maintaining the same site and the same precision. By splicing the common feature points, the Faro scanning point cloud data to Leica scanning data is spliced together, and the error of multi-point and multi-point registration is tested under the premise of single point and single point registration, so that the local coordinate system can be integrated high-precision and high-efficiency conversion.

Figure 3. Leica (left) faro (right)

## 3.3 *Technical applications*

### 3.3.1 *Data processing*

Using the Gaussian filtering algorithm, the original point cloud data is carefully denoised and the data is reduced by setting the curvature sampling mode to improve the data processing speed.

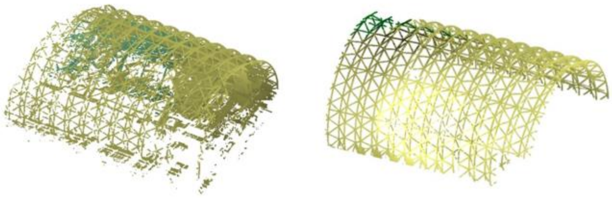

Figure 4. Raw point cloud (left) after processing point cloud (right)

### 3.3.2 *Data Registration and Accuracy Analysis*

Because the enclosure structure is a curved mesh and the members are all round pipes, point cloud splicing is carried out at the node of the intersecting pipe. The central line of the cylinder is obtained by the cylindrical fitting of the circular tube at the node, and the coordinate of the intersection point is obtained by the intersection of the two lines.

The point cloud registration steps are as follows:

(1)Acquisition of round tube centerline by feature fitting

(2)Extract the centerline of the intersecting circular tube and obtain the intersection point through the intersection of the straight line

(3)Extract intersection coordinates and input coordinate transformation matrix

(4)By optimizing the algorithm, the objective function is minimized and the conversion parameters are obtained

(5)The point cloud registration is obtained according to the error evaluation function

(6)Error meets required output result, otherwise return to third step

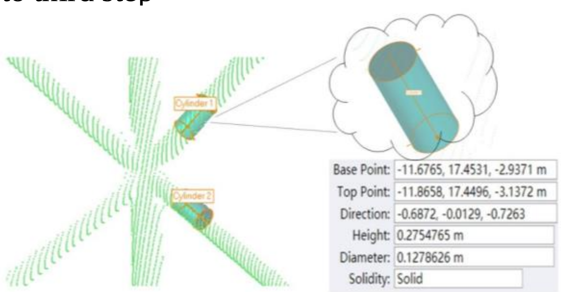


Figure 5.Circular fitting and coordinate information

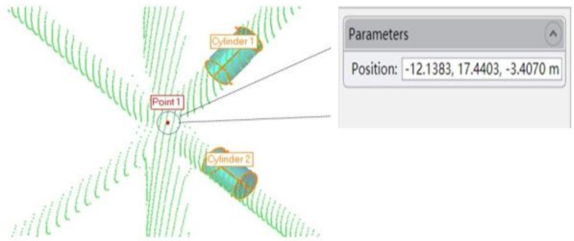


Figure 6. Extraction of intersection infomation

There are 7 groups of feature points are extracted for point cloud registration, coordinate infomation is extracted and deviations are calculated. The results are as follows:

Table 1 Corresponding characteristic point deviation

| group indication | deviation | | | |
|---|---|---|---|---|
| | Δx/(m) | Δy/(m) | Δz /(m) | d/(m) |
| 1 | 0.0006 | 0.0003 | 0.0007 | 0.000969536 |
| 2 | 0.0007 | -0.0009 | -0.0008 | 0.001392839 |
| 3 | -0.0007 | 0.001 | 0.0006 | 0.001360147 |
| 4 | -0.0006 | -0.0001 | 0.0011 | 0.001256981 |
| 5 | 0.0008 | -0.0009 | -0.0007 | 0.001392839 |
| 6 | -0.0009 | 0 | -0.0009 | 0.001272792 |
| 7 | -0.0002 | 0.0004 | 0.0007 | 0.000830662 |

The above results show that the x-direction deviation between the seven groups of corresponding feature points of two point clouds is between 0.2mm-0.9mm, the y-direction deviation is between 0mm-1mm, the z-direction deviation is between 0.6mm-1.1mm, and the calculated corresponding point spacing is 1.4mm, which meets the precision requirement with this project.

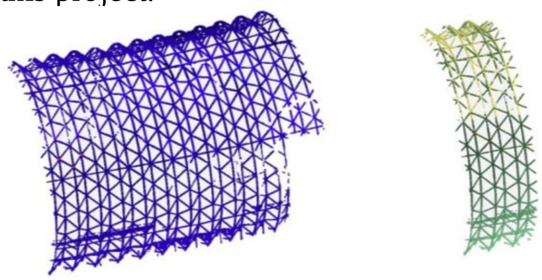

Figure 7. Faro Scanning Model (Left) Leica Scanning Model (Right)

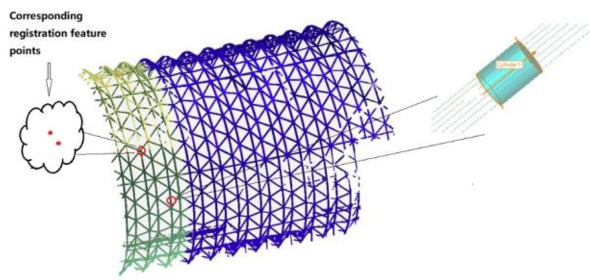


Figure 8. Post-registration point cloud model

After the registration model is randomly fitted to multiple columns in the common part, its diameter is obtained, and the fitting diameter is compared with the standard diameter to evaluate the point cloud registration accuracy.

Table 2 Diameter contrast deviation

| Column No. | $R_I$/（m） | $R_F$/（m） | $E$/(m) | $R_P$/（m） | $W$/（m） |
|---|---|---|---|---|---|
| **1** | 0.19008 | 0.19008 | 0.19008 | 0.18968 | 0.00040 |
| **2** | 0.19233 | 0.19233 | 0.19233 | 0.19250 | -0.00017 |
| **3** | 0.19450 | 0.19450 | 0.19450 | 0.19388 | 0.00062 |
| **4** | 0.19165 | 0.19075 | 0.19120 | 0.19129 | -0.00009 |
| **5** | 0.19429 | 0.19491 | 0.19460 | 0.19491 | -0.00031 |
| **6** | 0.19263 | 0.19453 | 0.19358 | 0.19412 | -0.00054 |
| **7** | 0.19456 | 0.19598 | 0.19527 | 0.19673 | -0.00146 |
| **8** | 0.19016 | 0.19148 | 0.19082 | 0.19164 | -0.00081 |
| **9** | 0.19445 | 0.19443 | 0.19444 | 0.19494 | -0.00050 |
| **10** | 0.18671 | 0.18618 | 0.18645 | 0.18653 | -0.00009 |
| **11** | 0.19494 | 0.19498 | 0.19496 | 0.19598 | -0.00103 |
| **12** | 0.19132 | 0.19129 | 0.19131 | 0.19134 | -0.00003 |
| **13** | 0.19298 | 0.19376 | 0.19337 | 0.19488 | -0.00150 |
| **14** | 0.19263 | 0.19453 | 0.19358 | 0.19412 | -0.00054 |
| **15** | 0.19470 | 0.19444 | 0.19457 | 0.19318 | 0.00139 |

The above results show that the registration deviation value is between 0.03mm and 1.5mm, and most of them are controlled within 1mm, and the point cloud registration effect meets the engineering requirements.

By comparing and analyzing the point cloud registration accuracy from the above two aspects, the results all meet the engineering requirements, so this method can realize the fast scanning and accurate positioning of large volume components.

## 4. ENGINEERING APPLICATIONS

### 4.1 *Reverse modeling*

Through the fusion application of the two instruments, the point cloud data of the enclosure structure are obtained efficiently and completely. each circular tube centerline is quickly extracted by the algorithm, and the cross section information is given to generate the reverse model(Wang,et.al.2017).

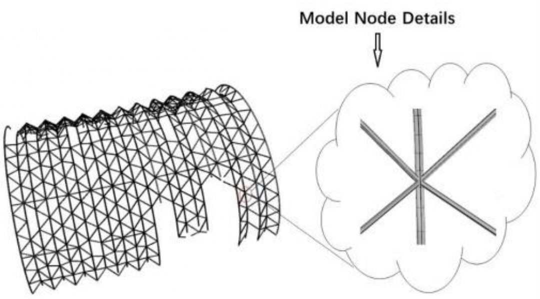


Figure 9. Reverse model of enclosure structure

### 4.2 *Deviation analysis*

The point cloud model obtained by this method can be compared and analyzed. Taking the design model as the reference object and the point cloud model as the test object, the three coordinate axis direction deviation of each node position is obtained by contrast analysis, and it is transferred with the reverse model of the enclosure structure to the site construction side and the curtain wall designer for reference adjustment, so as to play a guiding role in the later curtain wall installation.

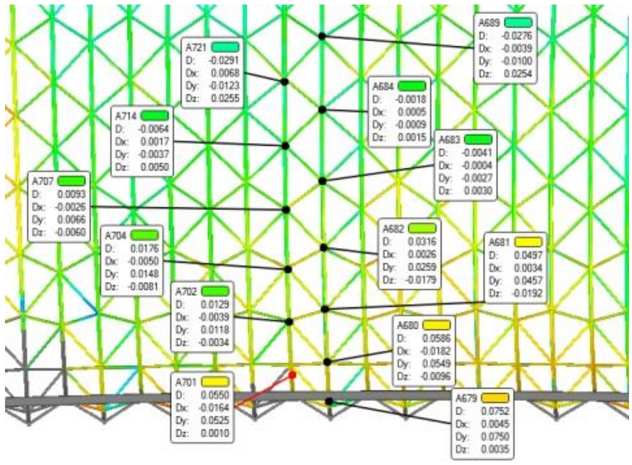


Figure 10. Comparison of Deviations

## 5. CONCLUSION

The implementation of high-precision coordinate system conversion algorithm and fast acquisition of point cloud data is decisive for high-efficiency, high-precision and all-directional acquisition of point cloud model with large-scale heteromorphic structure. It provides data support for reverse modeling and deviation comparison analysis, greatly expands the application range of 3D laser scanning technology and the stability, reliability and application range of data, and plays a more efficient role in engineering.


## 6. ACKNOWLEDGMENTS

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