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Automatic Detection Method for Large-Volume Embedded Parts Based on Laser Scanning

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Abstract. The embedded part (EMP) is a structural form in a building and plays an important role in the fixation of a structural or a non-structural member. After the initial installation, the popular detection method of the EMPs is to use the total station for single-point diagnosis. Due to the difficulties in point-by-point measurement and feature points selecting, it is sophisticated to ensure accuracy and efficiency in the detection process of large-scale EMPs. In order to solve the above issues, this paper proposes an automatic panel detection method for EMPs: (1) 3D laser scanning is used to obtain the actual coordinates of EMPs; (2) Developed algorithm is made to match the coordinates between design and measured data to calculate construction error; (3) Further use of the optimization algorithm to adjust the attitude of the point cloud, minimize the construction error and give the adjustment guidance of EMPs. A case study indicates that the efficiency is improved by about five times compared to the total station technique, and the number of EMPs need to be adjusted is greatly reduced. This method is of great significance for the high-volume component precision installation project.

1. Introduction

Embedded parts (EMPs) play a critical role in large structures and special buildings (such as laboratory, airport etc.), and their installation accuracy directly determines the safety of the joint framework. The chain reaction caused by the error of the installation position directly gives rise to the structural damage even destruction, which could bring about incalculable injury and estate loss. How to achieve accurate EMPs setting up is a technical problem facing the construction industry. Among them, high-precision detection and arrangement after the preliminary fixing is the key to meeting the construction requirements and ensure the quality.

In this paper, a 3D laser scanner is used to collect 350 sets of EMPs of the Bridge Laboratory in Chongqing Jiaotong University. On this basis, a large number of spatial point clouds are applied for rigid component coordinate, then combined with computer programming. An efficient and automatic batch detection method has been proposed in this paper. Figure.1 shows the research procedure overall. The result of the research demonstrates that it can improves the inspection and adjustment efficiency as well as ensure the accuracy simultaneously.



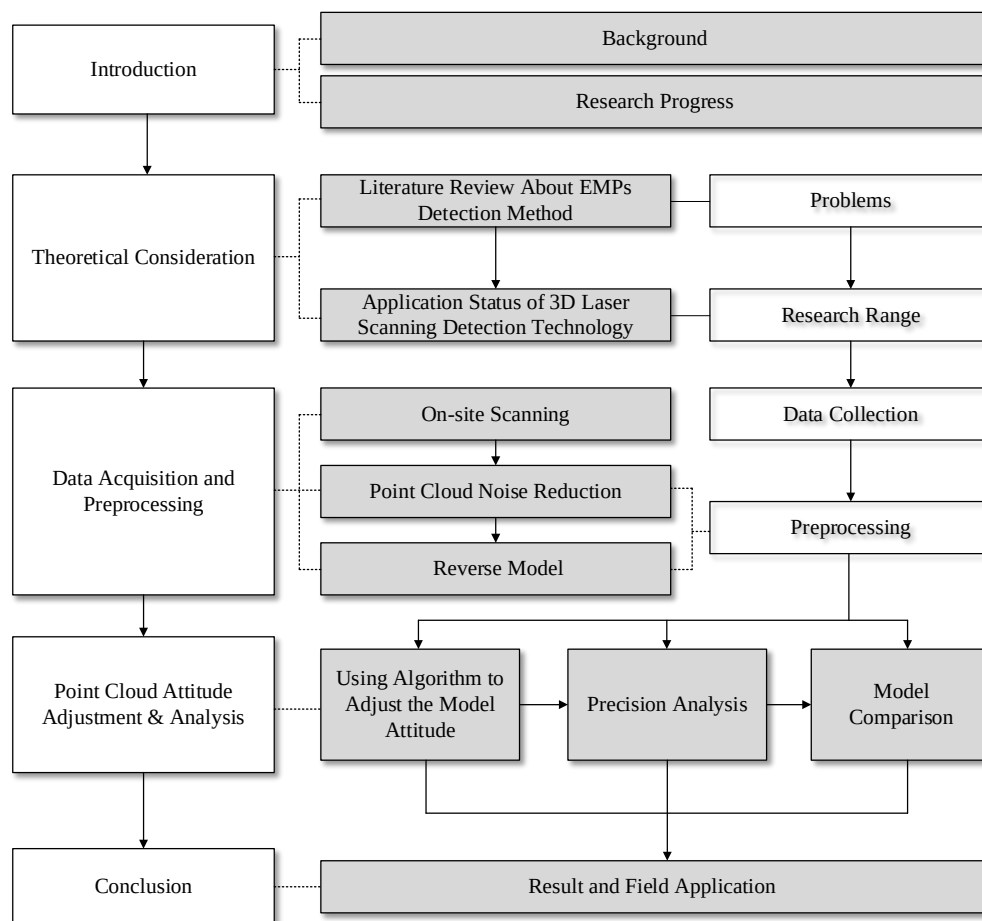


Figure 1. The flow of the research

2. Consideration of the current technologies

Building must be constructed with high precision, which means that the position and elevation of the EMP must meet the requirements. For this purpose, the surveyor is required to measure the spatial position of the EMP before the next component assembling. Unfortunately, this work is time consuming using existent methods, especially when the building is designed with a large number of EMPs. Presently, a total station is of large-scale use to assess the VPOINT one by one, then compare it with the design coordinates. At the meantime, 3D laser scanning is also on the pilot applications in building measurement. Table 1 outlines the pros and cons of above technologies [1,2]. There are a lot of limitation with this traditional method though it is of maturational theory, such as time and labor consuming. Above all it cannot cope with the large quantities of EMPs;

Through the literature review, Li Fengjun [3] established a control network based on the control piles, and adopted the method of erecting fixed brackets to locate the whole EMPs. Although it guarantees the accuracy of the EMPs, there are still some defects: 1) The central point of the EMPs cannot be measured directly, which degrades the positioning accuracy. 2) The EMPs have been detected one by one with total station, the efficiency cannot meet the norm. Tuo Lei [4] introduced a continuous tunnel section interception method based on point cloud, which used a restricted least squares and random sampling consistency algorithm. But it still has not overcome the problem of point cloud stitching accuracy. Li Shen [1] collected point cloud data with 3D laser scanner for a temple by setting the targets masterly, based on which wall thickness, roof depth and other data had been obtained precisely utilizing jointed point clouds inner and outer surface. It is impossible through traditional surveying measures. Glenda K Mayo [5] induced a case study in the application of a historic church disaster, which was documented with the

beneficial applications (such as safety and time savings) as well as what the authors believed to be future research areas for similar projects. He also reviews scanning industry applications and some improvements for precision measurements.

Table 1. The pros and cons of different technologies

Technology	Pros	Cons
Total Station	Easy to carry	Time consuming
	Mature technology	Lower accuracy
	Cheaper equipment	Unstructured data
		Labor intensive
		Unfit for large-scale areas
3D Laser Scanning	Large amount of data (Accidental error relatively reduced)	Costly equipment
	High precision (sub-millimeter)	High level technology requirement
	Full-automatic data collection	
	Visualization	

In current surveying, the features of the building are analyzed and extracted for detailed surveying with human brain, which gives rise to the subjective measurement result. Furthermore, the unstructured data from traditional methods is difficult to be classified and filed. The advantages of laser scanning, including high accuracy, large volume and visualization, and its numerous applications have made potential solutions to the above problems in modern construction.

3. Methodology

Since the foundation for follow-up structural installation, the accuracy of the EMPs installation determines the safety of the structure directly. For the EMPs' spatial position, the method with 3D laser scanning proposed in this paper contains the following steps: (1) On-site scanning. Due to the complex surrounding at the construction site and the huge volume of EMPs, it is of great significant to select the setting site during data collection. The principles will be covered in section 4.1, which illustrate how to set the measurement system. (2) Point cloud pre-processing. The point cloud collected on site may be separated in multiple parts since the large volume and instrument limitations. It thus requires pre-processing before the next accurate analysis. How to proceed with this step will be elaborated in Section 4.2. (3) Reverse modeling and attitude adjustment. In order to obtain the results of installation deviation of EMPs in the field, this paper establishes the solid model of EMPs with BIM technology based on the pre-processing, which is used for three-dimensional comparison with the design model. (4) Results evaluation. The test results are discussed according to this methodology, as well as the proposed adjustments with a case.

4. Case study

These is a large laboratory under construction in Chongqing Jiaotong University, Chongqing, China (As Figure.2(a) shows. It needs to setup 2,000 sets of counter-force saddles (EMPs) for educational research and experiment. After the installation is completed, it is necessary to ensure whether the EMPs meet the quality requirements: 1) The allowance error of the horizontal distance between the central point of the EMPs roof and the theoretical value is 2mm; 2) the permissible deviation of the verticality is 1/1000 (The tolerance value of the verticality indicates that the angle between the axis of the EMPs and the plane minus 90, the percentage of the result); 3) the allowable deviation of the top plate elevation is 3mm. Figure.2(b) shows the first batch of 350 sets EMPs which needs to be set.

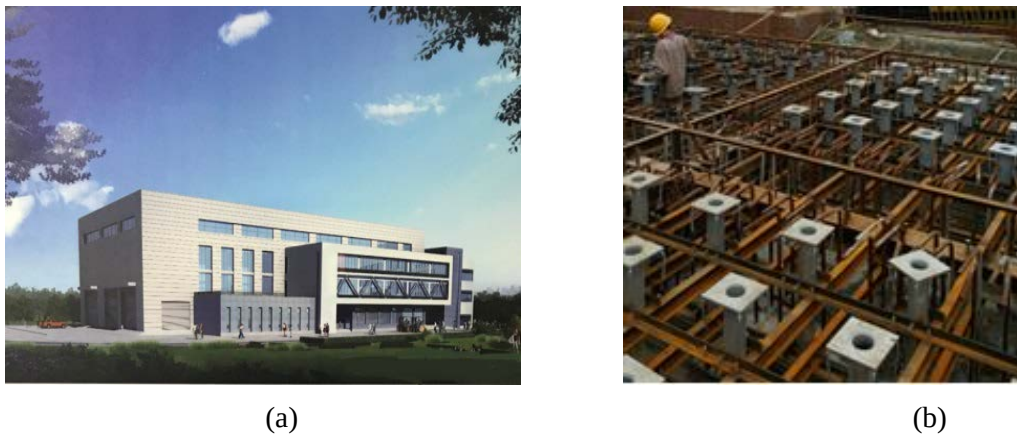


Figure 2. (a) Bridge laboratory sketch; (b) EMPs (counter-force saddles) installation site

4.1 Onsite scanning.

In order to get higher precision data as much as possible and reduce the work during the post matching, the point cloud collection must comply with some rules. Considering the surrounding on site, the target ball needs to be placed in the appropriate position; at the same time, scanner parameters need to be set in terms of the situation, which includes: pixel pitch, scan rate, and resolution.

Pixel pitch should be determined by the distance between every single station, which must guarantee the minimum gap beneath the allowance error within two different points. Not only the time consuming should be considered, but also the precision needs to be ensured, which decides the scan rate. At the same time, resolution of points is related to the pixel pitch, both of which determined the later process.

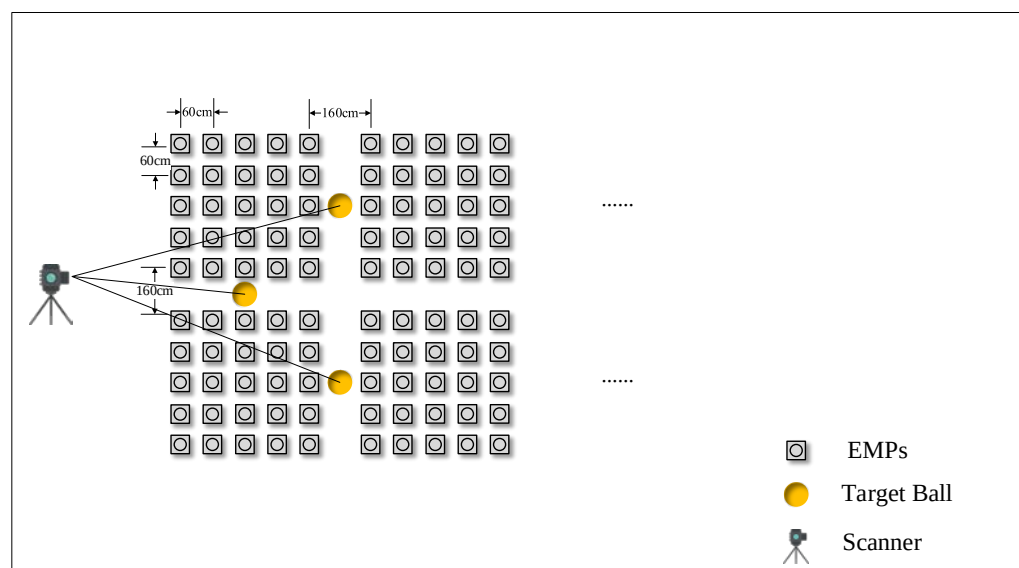


Figure 3. Scanner setup diagram

Figure.3 indicates the layout and circumstances on construction site, FARO X330 3D laser scanner is used in the scanning work. With four target balls keeping stationary between every two stations, the point cloud data with common points is obtained, which provides a basis for the later multi-site cloud splicing. In this whole collection process, six station locations were changed in totally, which brings about six stations of data.

4.2 Point Cloud Pre-Processing

After point cloud obtained from the above steps, it needs several processing to ensure standard requirements for inspection, including: registration, noise eliminate and converse modelling.

Table 2. Installation deviation analysis data before algorithm processing

Serial Number	Deviation		Serial Number	Deviation		Serial Number	Deviation		Serial Number	Deviation	
	X	Y		X	Y		X	Y		X	Y
3	-0.0005	-0.0026	32	0.0005	0.0021	63	0.0017	0.0023	85	0.0006	0.0023
5	0.0034	0.0010	39	0.0006	0.0038	64	0.0014	0.0027	86	0.0025	0.0019
7	-0.0003	0.0036	40	0.0009	0.0039	65	0.0011	0.0026	87	0.0019	0.0023
8	0.0007	0.0027	43	0.0028	-0.0001	68	-0.0004	0.0024	88	0.0019	0.0035
11	-0.0003	0.0032	48	0.0005	0.0022	69	0.0001	0.0034	89	0.0022	0.0038
13	-0.0012	0.0034	50	0.0030	0.0004	71	0.0021	0.0027	90	0.0007	0.0022
15	0.0000	0.0024	51	0.0008	0.0026	72	0.0008	0.0027	94	0.0011	0.0022
16	0.0004	0.0023	52	0.0016	0.0024	73	-0.0004	0.0031	97	0.0009	0.0028
21	0.0053	0.0004	53	0.0012	0.0024	74	0.0016	0.0032	98	0.0001	0.0026
22	0.0018	0.0035	54	0.0018	0.0026	75	0.0010	0.0022	99	-0.0008	0.0021
25	0.0015	0.0021	55	0.0007	0.0025	76	0.0020	0.0025	100	0.0006	0.0020
28	-0.0001	0.0021	58	-0.0009	0.0021	77	0.0007	0.0025			
29	0.0015	0.0044	61	0.0010	0.0029	78	0.0010	0.0023			
30	0.0005	0.0029	62	0.0001	0.0022	80	0.0009	0.0032			

As it indicates in Figure 4(a), the first thing is to register the six different parts of point cloud. Thanks to the common points on the same target ball between different station, registration can be done by searching for the public surface and points among them using presented means; At the same time, owing to the irregularity of point cloud density and the outliers as well as noise caused by occlusion and other problems, the point clouds need noise reduction. Firstly, unrelated large number of point clouds outside the scene can be deleted manually; then this paper builds a KD-tree for denoising work [6,7] for the disordered point cloud in the field:

- (1) Generate a KD-tree according to the point cloud data, and establishing a topological relationship of the point cloud;
- (2) Find the neighbor of every point;
- (3) Calculate the average distance between the point and each point in the neighbor;
- (4) Determine whether the average value exceeds a threshold value: if yes, removed this point.

Figure.4(b) shows the result of reduction. Obviously, the extraneous point cloud has been eliminated. After these processes, the EMPs model could be established from the point cloud. The spatial plane has been constructed below:

$$Ax + By + Cz + D = 0 \quad (1)$$

Assuming it is the plane equation of the EMPS' surface as above, and the parameters A , B , C , D could be calculated by the principle of least squares method. The space surface has been fitted with the top plate and the cylinder of EMPS' point clouds as Figure.4(c) shows.

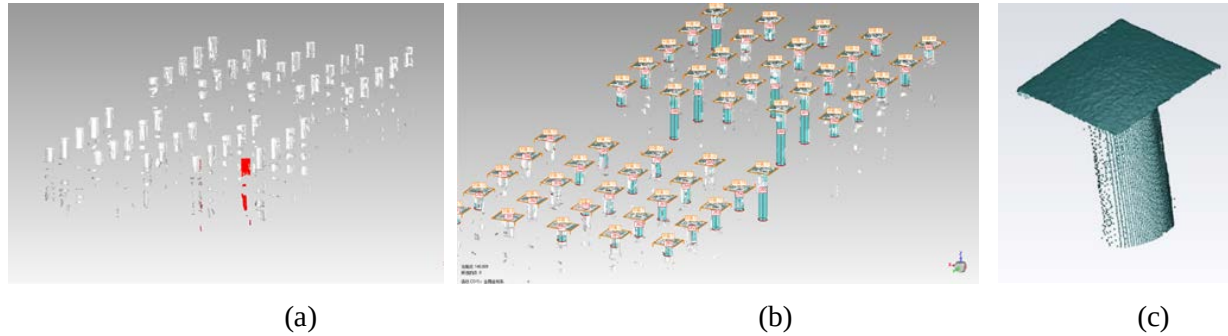


Figure 4. The point cloud (a) before reduction; (b) after reduction; (c) reverse model

Considering the design data as a reference, the central coordinates and normal equation of the EMPS are extracted from the point cloud. After that, the installation deviation is gained by means of comparing on-site data with reference point clouds. The results are shown in the Table 2 below.

From the chat, it can be concluded that the construction quality does not meet the requirements: The selected 100 sets of EMPS have different degrees of error in X and Y aspects, which means constructor must adjust them to make it below the limitation. However, there will be a mass of work owing to the errors from the test results as well as lacking of exact guidance. What the constructor need emergently is a fast and accurate adjustment method.

4.3 Point cloud attitude adjustment and analyze

In order to solve the issue from what discussed above, the improved ICP algorithm [8-9] is applied for the attitude adjustment. Through rotating and translating the plane, the EMPS' reverse models are corrected as much as possible in an optimized way. According to the algorithm, the coordinate transformation parameters R (rotation matrix) and T (translation matrix) are obtained through the methodology, so that the distance of 3D data under the two viewing angles is minimized with constantly iteration. Ultimately, the coordinate system is unified in two different point cloud parts. The main steps are as follows:

- Matches the closest point in the reference point cloud (or selected set) for each point in the target point cloud;
- Use Equation 2 to find the rigid body transformation parameters that minimize the root mean square (RMS) of the corresponding point pairs: coordinate transformation parameters R (rotation matrix) and T (translation vector);

$$\sigma = d(\vec{p_i} + \vec{q_j}) = \sqrt{((x_i - x_j)^2 + (y_i - y_j)^2) + (z_i - z_j)^2} \quad (2)$$

- Use the transformation matrix R and T to convert the target point cloud;
- Iterate until the condition for terminating the iteration is satisfied (the number of iterations or the error is less than the threshold)

Regarding the calculation of the matrix R and T , this paper utilizes the classical least squares (LS) principle with MATLAB programming. The LS principle is an optimal estimation technique introduced by the Maximum Likelihood (ML) when the random error is Normal distribution, which minimizes the sum of the squares of the measurement errors.

This paper selects the coordinates of the central point of the EMPS' top plate as the representative. It has been set that: the true central point position coordinate is set P , while the ideal central point position coordinate (from design information) is Q :

$$P=\{(x_i, y_i), i=1,2,3,...n\}$$

$$Q=\{(x_i'', y_i''), i=1,2,3,...n\} \quad (3)$$

The destination is to achieve the best match, coordinate transformation is employed so that it can align as much as possible between the two set, thus minimizes adjustment of the EMPs.

$$Q=PR+E \quad (4)$$

Among the equation (4), E is the error matrix while R is the rotation matrix:

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix} \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ T_x & T_y & 1 \end{bmatrix} \quad (5)$$

The following equation (6) can be available from formula (5):

$$E=B-AR \quad (6)$$

In order to find the matrix E , the sum of the squares of the two norms of E needs to be minimized:

$$R_m = \text{Min}\{E, \|E\|^2 = \|B - AR\|^2\} \quad (7)$$

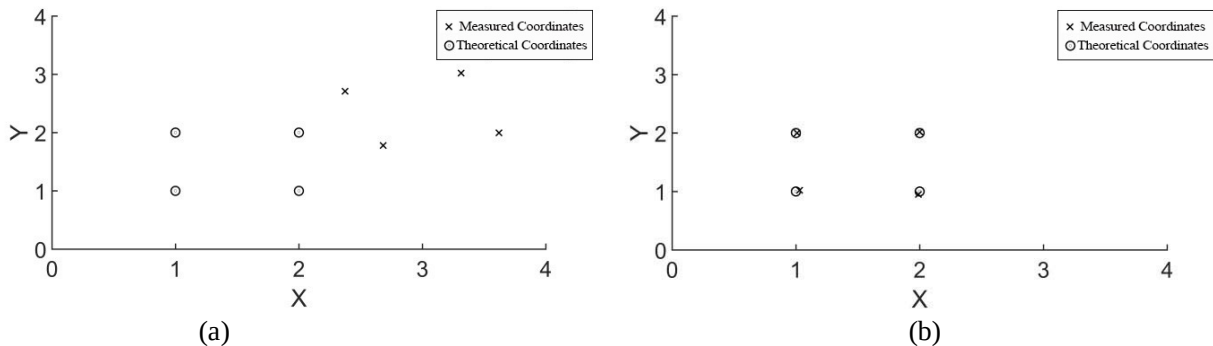


Figure 5. Using an algorithm to adjust the EMPs, before (a); and after(b)

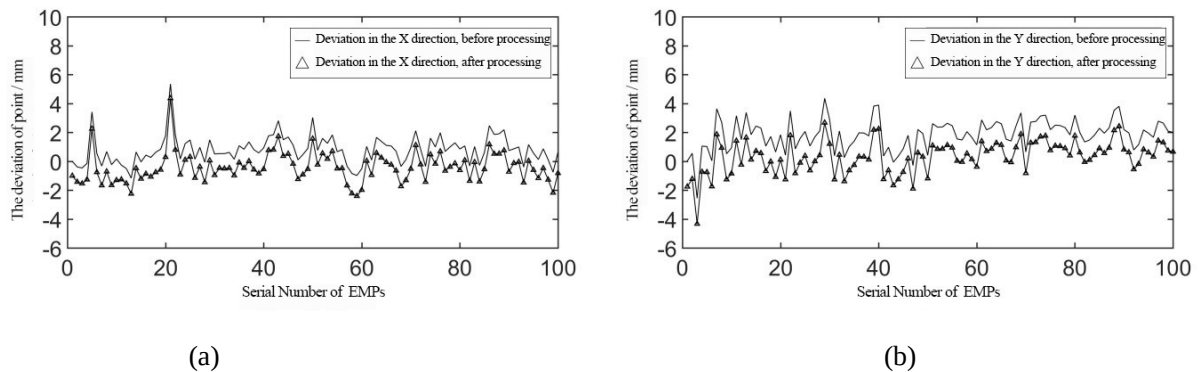


Figure 6. The deviation after algorithm processing. (a) X direction;(b) Y direction

When E is the smallest, it means R and T are found. Through computer programming, the effect before and after adjustment is as shown in Figure.5. It is obvious that the measured coordinates are coincide with the design values after the algorithm, which indicates that the number of adjusted EMPs can be minimized and the workload can be reduced largely. In fact, all 350 EMPs are adjusted and compared to the design

values. The result manifests that the deviation from the design value is significantly reduced, and only 10 EMPs need to be adjusted after using the algorithm (Figure.6).

5. Conclusion

Regardless of whether the algorithm is used, the shape of the deviation curve of the EMPs is similar, which means that the algorithm can only change the magnitude of the deviation and does not change the shape difference between the whole EMPs' theoretical control network. Both methods are reliable (Figure.6). But, before the algorithm is processed, the number of EMPs needs to be adjusted accounts for 41.4% of the total, and is reduced to 12.3% after being processed by the automated algorithm.

The method proposed by this paper could improve the detection precision of the EMP, greatly reduce the workload in the field, and provide a data reference for the detection and adjustment of the EMP. The use of 3D laser scanning technology and point cloud processing algorithm can greatly improve the efficiency in the civil engineering construction and detection. This will have a profound impact on future detection methods.

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