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Applying BIM and 3D laser scanning technology on virtual pre-assembly for complex steel structure in construction

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Abstract. Steel structure needs to be assembled before the components are transported to the site to ensure the installation of the steel structure successfully. The traditional assembly is a physical assembly method, which needs an amount of equipment, occupies large areas and can be labor and time-consuming. To address these issues, industrial photogrammetry has been developed to acquire data, and the steel structure has been virtually assembled in a virtual environment. The high-precision data acquisition of steel components is now carried out by using 3D laser scanner, and therefore, the feature data of those components can be automatically extracted by programming. As a result, the accurate linear shape of the post-splicing components can be extracted after completing the precise assembly of the steel structure in a virtual environment, which is significant for the subsequent mechanical analysis.

1. Introduction

The research described in this paper aims to explore an efficient and accurate digital pre-splicing method. The 3D laser scanning is used to obtain high-quality, all-round 3D digital models of building components, and then numerical analysis processing is performed by MATLAB and extract key parameters, such as bolt holes. In the computer, we need to adjust the posture of the splicing component to predict whether the splicing component can be spliced smoothly.This is substantial to achieve the purpose of predicting whether the construction is smooth.

Previous experience and research have shown that before the components are transported to the site, the steel structure needs to be assembled to ensure smooth installation on the construction site. Trial assembly requires sufficient space, labor, and almost the same mechanical equipment as the site, which accounts for a large total cost of manufacturing steel components (10%-25% of the total cost)[1]. Compared with the trial assembly, when the steel component is completed, the component feature is acquired by a data acquisition, and then the computer program is used to simulate the splicing posture, and the component which cannot be spliced regardless of the posture is subjected to the reverse field

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processing. To achieve the effect of predicting whether the component meets the splicing requirements this method of virtual assembly is being applied by more and more scholars.

2. Literature review

Virtual pre-assembly is the current development trend of the construction industry. Some engineering projects in China have already applied this method to guide the construction, and achieved some good results[2-4]. However, there are some limitations of data acquisition methods, many engineering cases only acquire data for a small number of key control points. To achieve the all-round, high-efficiency, high-precision virtual pre-assembly effect, we must be more effective in grasping and utilizing data acquisition.

2.1 Engineering case

There are some representative virtual pre-assembly projects in China. Tang Jiyu [2]used the total station instrument to collect and install the components feature data at Kunming Airport. The corresponding model was established by computer, and the virtual pre-splicing was carried out based on the control points of the respective models. And achieved the goal of better prediction of smooth splicing. Li Yadong and others [3]in the Shanghai Center Building measured the various control points of the components (the outer contour feature points of the control points and the bolt hole group positioning points), and the pre-assembly was realized by coordinate transformation. Ding Yifeng [4]et al. used a similar principle to conduct a pre-study on the layer of the third ring of Shanghai Central Building. The general process of the case-study is:(1)Use the total station to measure the control points.(2)Splicing by coordinate transformation. With the continuous updating and (3)Development of data acquisition technology, comprehensive and accurate data acquisition is no longer a problem.

2.2 Industrial photogrammetry system

Among them, industrial photogrammetry system is a widely used data acquisition method, such as the CATS system [5]jointly developed by Yokogawa Bridge Corporation of Japan and Changgang University of Technology, the measurement system introduced by GOM [6]in Germany (0.2mm for 10*5*5m3 volume), V-STARS [7]measurement system of American GIS Company. In addition, the 3D photogrammetry system of Beijing Tianyuan[8], China, has a measurement accuracy of 0.1mm/4m. The XJTUDP three-dimensional optical point measurement system of Xi'an Jiaotong University [9]has a measurement accuracy of ±0.15mm/m. These industrial photogrammetry systems have high accuracy in data acquisition.

2.3 3D laser scanning technology

In recent years, the three-dimensional laser scanning technology which is known as "real-life reproduction technology" has been widely used in the construction industry. The general principle of 3D laser scanning is to use laser ranging to obtain a large number of accurate and dense 3D data information on the surface of the target object. Compared with the traditional measuring tools, it has a lot of unparalleled advantages which is fast, high precision and all-round. With the continuous development of 3D laser scanning technology, the scholars at home and abroad have made an in-depth application research. Xie Hongquan[10] et al. conducted a systematic test study on the accuracy of ground 3D laser scanner ranging accuracy. Based on Leica HDS Scan Station 2 three-dimensional laser scanning system, Li Haiquan [11] and others explored several important factors affecting measurement accuracy and its control methods. Cao Xiange [12]et al. through the study of a series of factors affecting the accuracy of 3D laser scanning in the application process, it is concluded that under the control of scanning distance, scanning point spacing, point cloud stitching accuracy and other factors, this will guarantee the accuracy of 3D laser scanners.

Compared to industrial photogrammetry, 3D laser scanning has many advantages:(1)Easy to operate(2)Can obtain large-volume component characterization information at the same time(3)High quality, all-round point cloud data can be obtained under certain measurement

In summary, under the conditions of guaranteed distance, scanning point spacing, illumination and other factors, a 3D laser scanner can be used to obtain high-quality, all-round digital models of building structures to meet the requirements of accurate extraction of data features. Moreover, the use of three-dimensional laser point cloud for component pre-assembly can intuitively check whether the steel beam can be successfully spliced. A real-world model of components formed by dense 3D laser point clouds—the rich BIM.

3. Methods

3.1 Virtual pre-splicing implementation model establishment

This part describes the steps of data acquisition, feature information extraction, and pose splicing of 3D laser scanning technology. For general components, virtual pre-splicing can be realized through these steps.

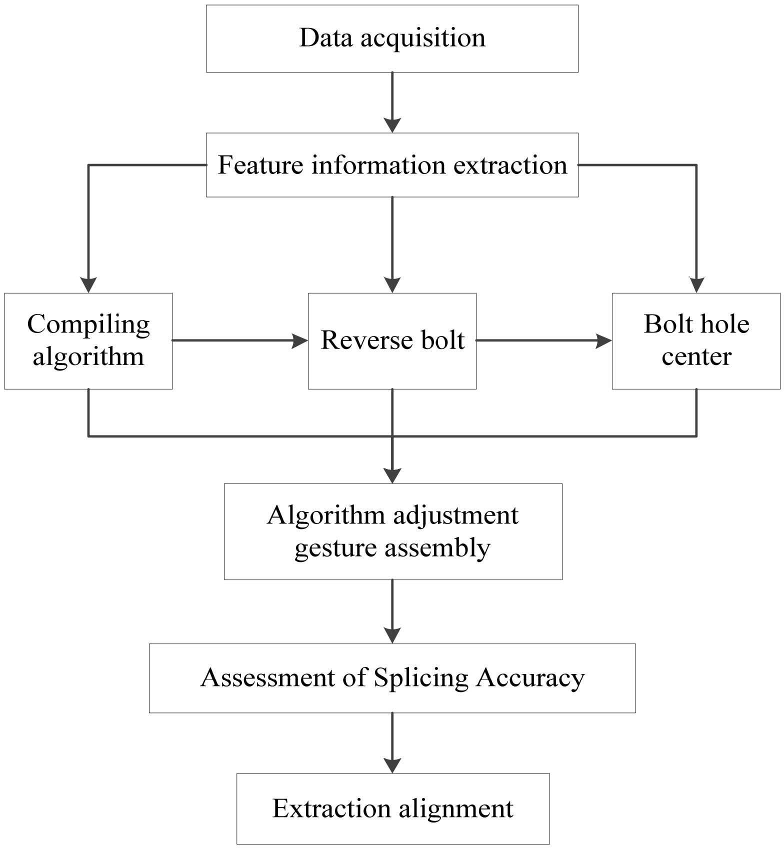

Figure 1.Virtual pre-assembly flow chart

*3.1.1 Data acquisition.*Use a better-performing 3D scanner (such as FARO330) to collect data on the components to be spliced. In order to ensure the quality of splicing, it must be controlled at a suitable distance, set appropriate scanning parameters and the temperature must be suitable. The target balls are guaranteed not to be arranged on the same line. In particular, focus on the splicing control area to ensure the quality of feature point extraction.

*3.1.2 Feature information extraction.*This step is a key step. Different components have different connection methods. Welded connection and bolted connection are the common connection modes of components, among which virtual pre-assembly is more meaningful for bolted connection.The key information of bolt hole is radius and center position. Independent coordinate system is established in the component itself, and the single bolt information is extracted by software programming, and the circle is fitted.In order to simplify the algorithm, the stereoscopic bolt hole cylinder is transformed into a plane projection through its own direction vector when fitting the circle.There are a few noise points in the bolt hole. The key is how to delete the noise points in the bolt hole through the idea of program iteration. The center radius obtained from a large number of dense high-quality point clouds can ensure the high quality of virtual pre-assembly.

*3.1.3 Algorithm adjustment gesture assembly.*Italy *F.Case* [13]proposed a pre-assembly method based on bolt hole position, improved orthogonal Platts analysis method EOPA, using this method to digitally pre-assemble the Chernobyl nuclear power plant shield project successfully. This model also uses this classical algorithm to adjust the attitude of the circle coordinates of the extracted bolt hole point cloud to determine whether the two steel beams can be assembled smoothly.

Assuming there are P points, the measured coordinates and theoretical coordinates are expressed by matrix *A* and *B*, respectively.At the same time, the unknown rotation matrix is *T*, the unknown displacement vector is *t*, and the unknown error matrix *E*.

$$E = AT + jt^T - B \tag{1}$$

$$j_{p,1}=[1,1,1....1]^T$$

Take $S = A^T(I - \frac{jj^T}{p}) - B$, and perform matrix singular value decomposition (SVD) on {SST}and {STS}to:

$$T = VW^T \tag{2}$$

$$t = \frac{(B - AT)^T j}{p} \tag{3}$$

Bring *T* and t into the formula (1), you can get the error matrix *E*.

*3.1.4 Pre-assembled component linear extraction.*In the case of obtaining the final pose of the virtual pre-assembled structure, the component point cloud is used for linear extraction to prepare for the next stage of mechanical analysis.

3.2 Example

*3.2.1 Data acquisition.*Apply the above model to this example to illustrate its application steps. The Fujiang Bridge in Tongnan in Tongnan is 576m in length. The main bridge is a 57m+128m+220m single-tower and double-cable-plane composite girder cable-stayed bridge with 405 meters in length, 36.6 meters in width (including cable-stayed area) and 156 meters in height. Traditional total station can not effectively locate the location of bolt holes in steel beam splicing. The distance between bolt holes is 100 mm and the standard diameter of bolt holes is 16.5 mm. The distance between bolt holes is 100 mm and the standard diameter of bolt holes is 16.5 mm. In order to ensure that two adjacent steel beams can be spliced under the manufacturing line (stress-free line), it is necessary to pre-splice them in order to predict whether the construction can proceed smoothly.The way to collect data is like above, and will not be described here.

Figure 2.Steel beam

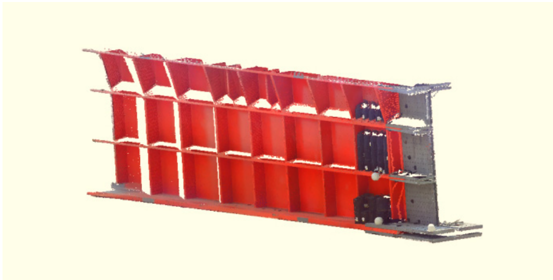

Figure 3.Steel beam point cloud

*3.2.2Data processing.*The end point cloud is extracted separately, and the bolt hole point cloud is obtained, and then the feature data extraction is completed. (1)Use MATLAB to program batch extraction bolt hole point cloud.(2)Use algorithm to delete the noise point cloud in the bolt hole in batches.(3)Fit the point cloud of a single bolt hole separately. The idea of fitting is to flatten the three-dimensional bolt hole point cloud, the cylindrical point cloud is converted into a plane bolt hole point cloud, which greatly simplifies the difficulty of cylindrical fitting.

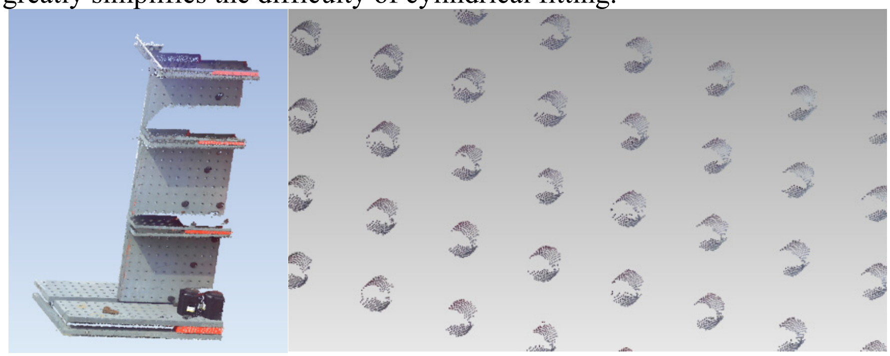

Figure 4. Steel beam end and bolt hole point cloud

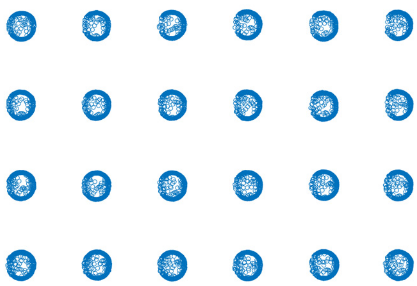

Figure 5. bolt hole point cloud

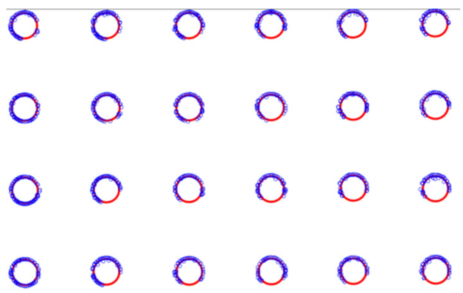

Figure 6. bolt hole point cloud fitting circle

The following are the coordinates of some bolt holes of the fitted steel beam:

Table 1. Reverse coordinates of partial bolt holes in two steel beams （m）

number	Steel beam 1			number	Steel beam 2		
	x	y	radius		x	y	radius
1	-0.00029	0.00011	0.01680	1	-0.00019	-0.0001	0.01682
2	-0.00088	0.10005	0.01680	2	-0.00042	0.1008	0.01625
3	-0.00053	0.20058	0.01662	3	-0.00054	0.20058	0.01665
4	-0.00040	0.3018	0.01645	4	-0.00079	0.30094	0.01629
5	0.09938	0.00012	0.01667	5	0.09981	0.00053	0.01676
6	0.09913	0.10020	0.01676	6	0.0996	0.101	0.01668
7	0.09918	0.20020	0.01676	7	0.09959	0.20093	0.01675
8	0.09896	0.29989	0.01665	8	0.0993	0.30159	0.01658

9	0.19921	0.00022	0.01671	9	0.1998	0.00109	0.01653
10	0.19917	0.10049	0.01674	10	0.19979	0.10122	0.01643

In addition, the difference between the fitting bolt hole radius and the standard radius is as follows:

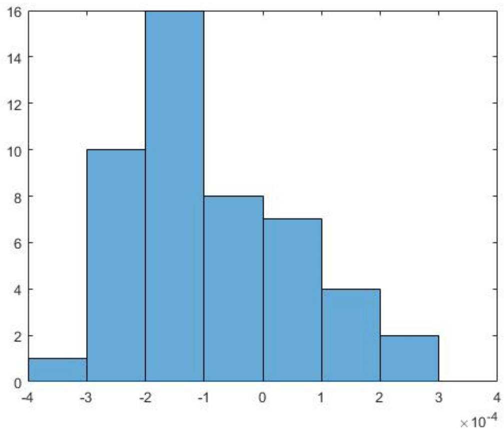

Figure 7. The difference between fitting bolt hole radius and standard radius(m)

*3.2.3Algorithm adjustment gesture assembly.*The virtual pre-splicing of two steel beams is carried out by using the above algorithm, and the deviation values of the X and Y directions of the bolt holes corresponding to the two steel beams after attitude optimization are counted. In order to study the assembling process of steel beams more visually, the corresponding point clouds were adjusted after adjusting the parameters by using the algorithm.

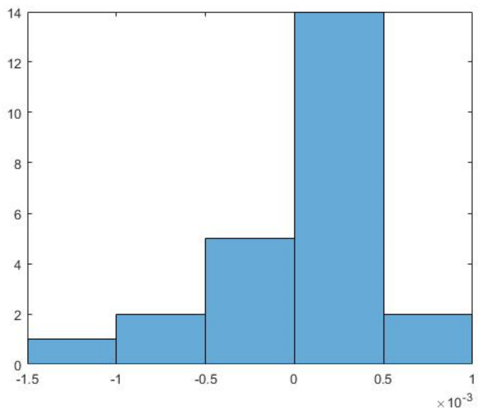

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Figure 8. X-Direction Deviation Value of Beam Corresponding to Bolt Hole

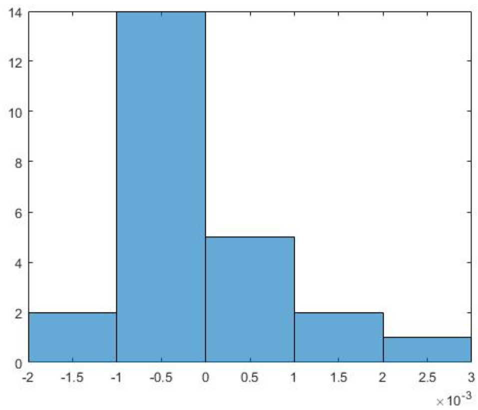

Figure 9. Y-Direction Deviation Value of Steel Steel Beam Corresponding to Bolt Hole(m)

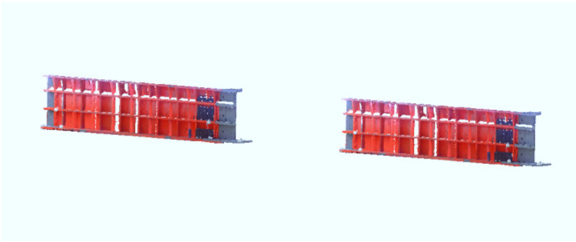

Figure 10. Two steel beams before splicing

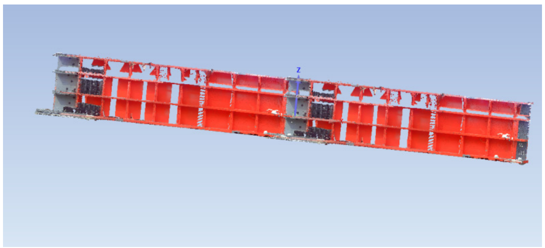

Figure 11. Two steel beams after splicing

*3.2.4 Pre-assembled steel beam linear extraction.*According to the adjusted point cloud attitude, two pieces of rigid beam line shapes are extracted. This line shape is an accurate actual line shape, and it is important to introduce it into the calculation of mechanical analysis software.

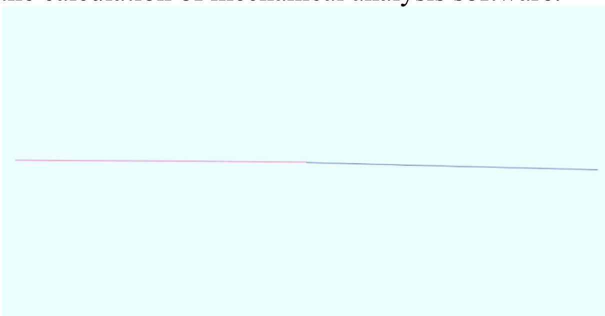

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Figure 12. two steel beam line shape

4. Conclusion

This paper proposed an efficient and accurate digital pre-splicing method, which can achieve that the numerical analysis software automatically extracts enough splicing feature point data, after obtaining the panoramic entity refined point cloud digital model. It has the advantages of not occupying space, ensuring the high-altitude dangerous operation, assembling smoothly, and predicting whether it can be spliced, compared with the traditional trial assembly. To be more specific, this method has the following characteristics: (1) The batch fitting of program automation and feature data are proposed, which greatly improves the efficiency. The traditional manual extraction of bolt hole features is far less efficient than the automatic extraction of features by the algorithm, which has far-reaching significance to ensure the duration of the project. (2)Based on the characteristics of a large number of precise point cloud fitting, the accuracy is guaranteed sufficiently. The fitting bolt hole radius and ideal radius are distributed in a normal way, and the deviation is within 0.4 mm, which shows that the fitting effect is good.(3)In the virtual pre-assembly of two steel beams, the data show that the deviation distribution in X and Y directions is less than 3 mm.(4)The precise alignment can be extracted from point clouds after virtual stitching, which has important guiding significance for mechanical analysis.

This method may need to be improved in the following aspects:(1)Noise points of a point cloud will affect the accuracy of fitting bolts, so how to reduce noise more effectively needs further study.(2)In this paper, the plane is used to replace the three-dimensional cylindrical analysis, while stabilizing the effective reverse cylinder, the default bolt hole sag meets the requirements, which requires higher construction technology.

Further research may be to extract relevant features by using artificial intelligence related algorithms, which is expected to further improve the efficiency and accuracy of feature data extraction.

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