POINT CLOUD SLICING-BASED EXTRACTION OF INDOOR COMPONENTS

Zhao. Jianghong [1,2,3,] Cui. Yuanyuan [1,3,]Niu. Xinyu [1,3,] Wang. Xin[1,3*,]Zhao. Yingxue [4,] Guo, Ming [1,3,] Zhang, Ruiju [1,3]
1School of Geomatics and Urban Spatial Informatics, Beijing University of Civil Engineering and Architecture, Beijing , China-zhaojiangh@bucea.edu.cn, 2108570020088@stu.bucea.edu.cn, niuxinyu0225@163.com, 1254952619@qq.com,1254952619@qq.com, guoming@bucea.edu.cn, zhangruiju@bucea.edu.cn
2Key Laboratory for Urban Spatial Information of the Ministry of Natural Resources, Beijing 102616, China
3Beijing Key Laboratory for Architectural Heritage Fine Reconstruction & Health Monitoring, Beijing 102616, China
4Guangzhou Panyu Polytechnic, Guangzhou , China-821862137@qq.com
* Correspondence: 1254952619@qq.com

KEY WORDS: Component Extraction, Point Cloud Slice, 3D Laser, Indoor Point Cloud, Overlay Analysis.

ABSTRACT:

Indoor point cloud data is easy to obtain and contains a large amount of data, but there is no connectivity, no structural attributes, and no semantic information between point clouds. It is very difficult to extract interior components. In order to solve the problem that it is difficult to extract the closed door in the indoor point cloud, and the indoor scanning point cloud data is noisy and redundant, a point cloud segmentation method is proposed to reduce the amount of data and the impact of noise. Because most of the indoor components are not on the same horizontal plane, different component information can be obtained by slicing the point cloud at different heights. In these slices, the component that always exists is the wall. By comparing other data with the point cloud data with a more complete wall, the required component can be extracted. The experimental results show that this method can accurately extract the indoor door component information and beam component information, providing a data basis for building model refinement.

1. INTRODUCTION

With the development of 3D point cloud data, indoor navigation is widely used in public places. This makes the establishment of indoor 3D point cloud models crucial (ZHAO Xu, ZHOU Keqin, YAN Li, & Fei, 2008). But usually, the indoor scene environment is more complex, the point cloud data obtained by scanning is more messy, and there are many objects and occlusion (Zhao Mengna, Hua Xianghong, Feng Shaoquan, & Bufan., 2020). As a result, the 3D point cloud has a large amount of data, redundant information, no connectivity between point clouds, no structured attributes, and no semantic information. The use of point clouds for 3D model reconstruction has also become a research hotspot and a difficulty in promoting (ZHAO Bufan, HUA Xianghong, XUAN Wei, CHEN Peng, & Ronghua, 2018).

Building components such as rooms, corridors, stairs, doors, and windows are important elements used to form a 3D model. In the current research at home and abroad, it mainly focuses on the research of wall line, doors and windows (Jianghong, Yan, Shuangfeng, Mingyue, & CHAOYANG, 2020; Lu Weixin et al., 2015; WEI Shuangfeng, LIU Minglei, ZHAO Jianghong, & Shuai, 2018). But it lacks the extraction of beam elements. As an important element of 3D modeling, the beam element is included in the indoor space, which makes it difficult to extract.In addition to beam elements, doors and windows are also key elements. It determines the connectivity between spaces and is the key to judging connectivity between spaces. The current door and window extraction method is based on the depth difference between the door and window and the wall. Zou et al. used the depth difference between the window and the wall to realize the identification and extraction of the window, and used the distance weighted reciprocal IDW interpolation method to generate the dual depth image of the building patch, and then processed the threshold segmentation, median filter smoothing, morphological Filtering, etc., find the point cloud and boundary within the window (Ji-wei; et al., 2020). In the case of window cavity, TIN is used to extract the boundary. Since the edge length of the window boundary points is much longer than the window surrounding points, the window boundary points are found based on this. Shen et al. proposed a 3D-2D-3D door and window detection algorithm in order to detect the door and window information in the indoor 3D scene(Le, 2019; Shen Le, Li Guiqing, Xian Chuhua, Jiang Yang, & Yunhui, 2019). Take a multi angle rotation photo in the 3D indoor scene point cloud model to obtain the 2D image of the point cloud; Then rough detection of door and window objects is carried out on the 2D image to obtain the approximate range of doors and windows in the image, and the 2D information is returned to the 3D point cloud data to obtain the local point cloud data containing doors and windows; Finally, the contour lines and intersections of the local point cloud data are extracted, and the location information of the door and window feature corners is obtained through optimization. U. Gankhuyag and J. Han simplified the input point cloud and generated new points from the simplified point cloud to fill in the plane as well as the missing parts in the nearby edges. The point cloud is generated as a 2D depth image applying CNN to detect the wall topology, and then the doors in each detected wall are detected by a template matching algorithm (Gankhuyag & Han, 2021). Reference extracts doors according to the topological relationship between doors and walls (Fan, 2019). First, the wall with the door is extracted, the data is projected, and then converted into a binary image, and the empty pixel in the wall is the door. However, this kind of door that is judged by the difference in depth can only be an open or half-open door, or a door with a significant depth difference from the wall. Otherwise, if the door closed by the detection data, the recognition rate will be greatly reduced.

To address the above problems, this study proposes a point cloud extraction method based on hierarchical slicing and stacking analysis（HS-OA）, which can extract the required elements by using the information of components of different heights to obtain the point cloud data of the complete wall. This method can simplify the complexity of building geometric feature extraction, obtain the information of interior elements such as beam elements and door elements, realize the detection of beam and door elements' positions, and provide data and model support for the realization of various indoor navigation functions such as indoor positioning, path analysis, and real-time navigation.

2. METHOD

2.1 Process Introduction

It includes the following three key parts: (1) First, the original point cloud is preprocessed, and the floor is divided by the point cloud statistical histogram to improve the processing speed of the original point cloud data. (2) According to different needs, use the point cloud slicing method to process indoor data multiple times, slice the point cloud multiple times, and extract the data of doors, windows and beams. (3) Use point cloud difference to process point cloud slices with door and window data and beam data, obtain door and window data and beam data, obtain position information of doors, windows and beams, and realize door and beam detection.

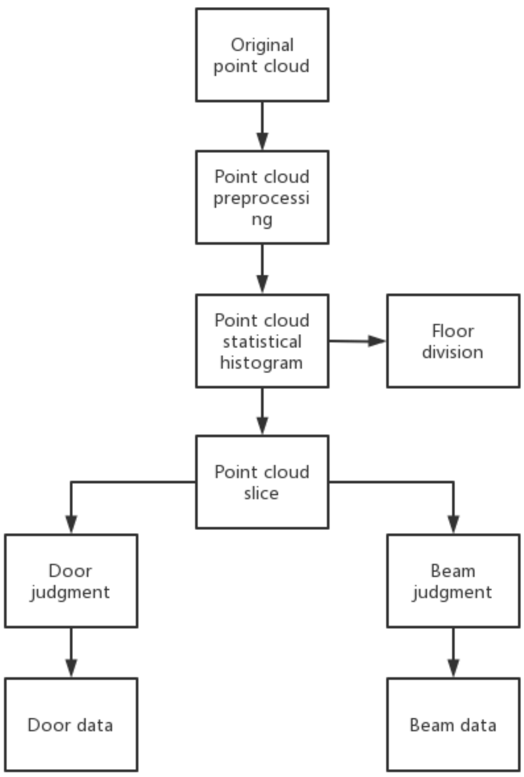

Figure 1. Overall process of experiment

2.2 Segmenting Floor Data Using Point Cloud Histograms

Since each floor in most buildings cannot guarantee the same room setting, which hinders the spatial division of indoor point clouds, it is necessary to divide the floors of the building first. For indoor point cloud data of buildings, Oesau et al. believed that horizontal structures such as ceilings and floors would generate a large number of samples with the same height when scanning (Oesau, Lafarge, & Alliez, 2014). That is to say, there are horizontal planes such as the ceiling and the floor in the building, which are parallel to the XOY plane, so the elevation values should be equal everywhere in these horizontal planes, and a large number of sample points with the same z value should appear in the point cloud. Based on this idea, this paper projects the point cloud to the Z axis to generate a point cloud density histogram, and horizontal structures such as the ceiling and floor will be displayed as the peak of the point cloud density histogram, thereby separating the single-story data.

2.3 Use point cloud slices to process data including doors, windows and beams

Due to the complex terrain, many ground objects and occlusion in the real space, there are a lot of noise in the scanning data, and the data will be broken or missing. This situation will cause the point cloud data to be very cluttered, which will affect the intensive reading and efficiency of indoor component extraction. However, most of these messy data exist in the space below 1.2m, so the point cloud with less noise is selected, which can reduce unnecessary interference and improve the accuracy and efficiency of building component extraction. As shown in the figure, Figure 2 is the data without removing the point cloud below 1.2m, and Figure 3 is the data with the point cloud below 1.2m removed. It can be seen that almost all of the noise interference is removed. However, there are still some debris with higher elevation values that will still have an impact.

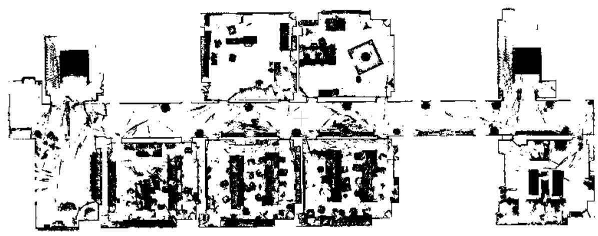

Figure 2. Data before segmentation

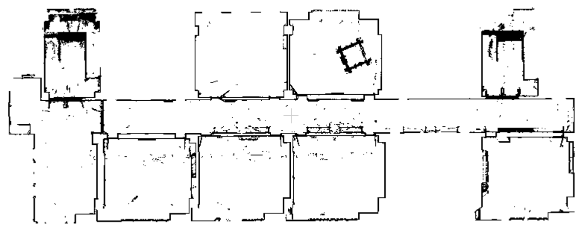

Figure 3. Data after segmentation

2.4 Extract Data of Doors, Windows and Beams Using Point Cloud Overlay Analysis Method

Because most of the indoor components are not at the same level, for example, the height of the door is generally 2m, the height of the window is generally 1.2-2m, and the height of the beam is generally 0.8m below the roof. To address this situation, this study slices point clouds of different heights to obtain different element information. As the wall is the main element of the slicing, this study compares the point cloud data with individual wall information with the point cloud data of the wall containing multiple elements to extract the beam and window and door elements.

Therefore, in this study, the point cloud data is divided into two types, one is the post-slice point cloud with the components to be inspected - the wall data with multi-element information. One is the contrast point cloud, that is, the point cloud with only wall lines. The comparison point cloud (point cloud with only wall lines) is called point cloud A, and the point cloud with components to be extracted is called point cloud B.

The specific process of HS-OA algorithm is as follows: input point cloud A and point cloud B. K neighborhood search is carried out with the point in point cloud A as the seed point. Calculate the distance between the point in the searched point cloud B and the seed point. If the distance is 0, the two points are coincident. If the distance is not 0, the two points are not coincident. The point coincident with point cloud A in point cloud B is the wall point, which can be deleted. The point not coincident with point cloud A is the point of the component to be extracted, and it is reserved. Finally, all points in point cloud B that do not coincide with point cloud A are output, and this point set is the extracted component data.

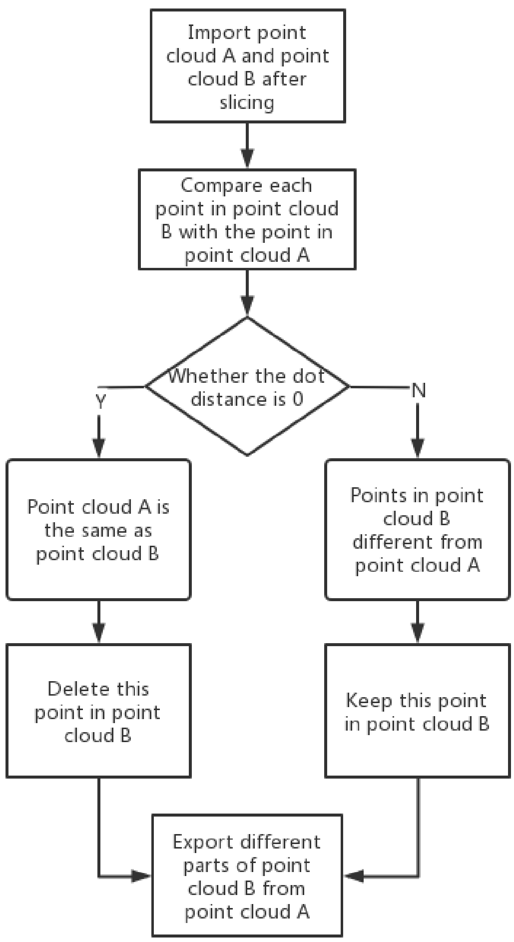

Figure 4. Point Cloud Overlay Analysis Process

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1 Study Area and Data Source

This article is written in Intel(R)Core(TM)i7-7700cpu@3.60GH z Under the environment of processor and 16.0GB memory Win dows10 operating system, the experiment is conducted with C+ + as the main programming language, CloudCompare as the mo del visualization software, and other third-party libraries.

The experimental data in this paper are collected from the first floor and the second floor of a teaching building in Beijing Jianzhu University. The data includes all accessible rooms on the first and second floors, and stairs connecting the first and second floors on the east and west sides. The measured point cloud data is shown in Figure 5. Data details are shown in Table 1.

The experimental data were obtained by TrimbleTX5, a ground laser scanner sold by Trimble Company in the United States. Data volume is 909MB. Although the indoor point cloud data used in the experiment has a high accuracy, due to the fact that it is measured data, the indoor data has a high complexity, and data occlusion is inevitable, resulting in data loss of varying degrees.

Data acquisitio-n method	Data volume	Indoor comple-xity	Point cloud missin g degree	Color infor-matio n	Content quanti-ty
Trimble TX5	909MB	High	High	RGB	Eight rooms on the first floor
					Six rooms on the second floor
					Stairs on east and west sides

Table 1 Information of Point Cloud Data

Figure 5. Field Data Collection on the First and Second Floors of Building F, BUCEA

3.2 Experimental Result

3.2.1 Stair Segmentation Experiment Results

Floor segmentation adopts the method of generating point cloud density histogram, that is, projecting the Z-axis of the point cloud image to generate a point cloud density histogram, and judging the position of the floor and ceiling from the fluctuation of the histogram.In the experiment, the elevation interval value is 10cm, and the unit is mm in the building point cloud data. As shown in Figure 6, the statistical results of indoor point cloud data by elevation range.It can be clearly seen that the "valley" in "peak valley peak" appears in the range of - 85~15.According to the manual measurement data, the ceiling elevation of the first floor is -126.38, and the floor elevation of the second floor is 30.164. Obviously, the interval - 85~15 can be used as the division boundary of floor division. The point cloud segmentation effect of the first floor (blue) and the second floor (orange) of College Building F is shown in Figure 7. The final segmentation effect is shown in Figure 8 and Figure 9. It can be seen that the first floor point cloud data is completely separated from the second floor point cloud data with clear edges, and the

https://doi.org/10.5194/isprs-archives-XLVIII-3-W2-2022-103-2022 | © Author(s) 2022. CC BY 4.0 License.

ceiling of each floor point cloud data is clearly visible. It can be seen that the floor segmentation effect of this method is good.

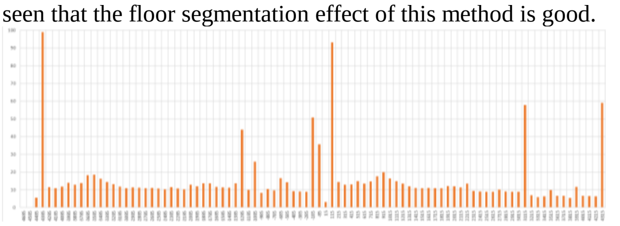

Figure 6. Point cloud distribution density histogram

Figure 7. The first and second floors of the divided building

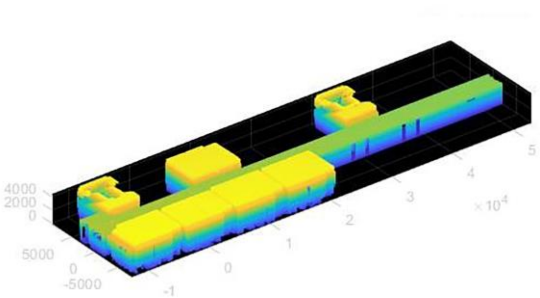

Figure 8. The second floor of the divided building

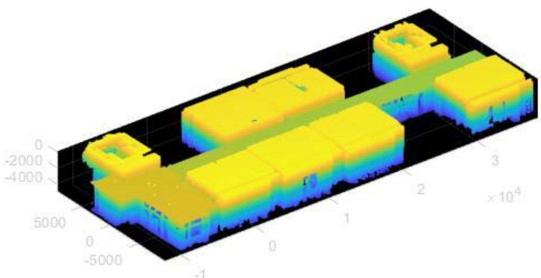

Figure 9. The first floor of the divided building

3.2.2 Extraction Experiment of Indoor Beam Components

Since the beam member is at the top of all members, it is selected to slice at 3.6m and select the slice with the beam plane position. After the point cloud is projected and dimensionally reduced, the "beam" will be reflected as a contour surface, as shown in Figure 10. Where the width of the point cloud is large, it is the beam.

Because there are different components between slice point clouds of different heights, the two parts of point clouds are overlapped, the wall of the upper point cloud will coincide with the lower point cloud, and the non overlapped part is the beam part. The wall line point cloud (as shown in Figure 11) is projected into a reduced dimension as a seed point. Judge the non coincidence part with the point cloud with beam component. Due to the complexity of the stairwell, no data will be extracted from the stairwell this time.

Because there are some other items in the space at the height of the beam, such as chandeliers, pipes, etc. These will affect the extraction results of the beam. As shown in Figure 12, after the removal of wall lines, there are still some fine data. It is obvious that point clouds of non beam data exist. According to the field inspection, this is a hot water pipe, which is at the same elevation as the indoor beam. Therefore, after the overlay analysis, the results are divided into regional growth segments. Analyze the segmented plane, remove some surfaces with small area and point cloud amount, and remove irrelevant information. As shown in Figure 15, this is the result after removing irrelevant information, and only the indoor beam exists.

Figure 10. Point cloud with beam part

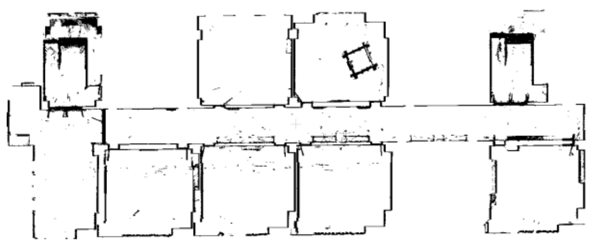

Figure 11. Wall line point cloud

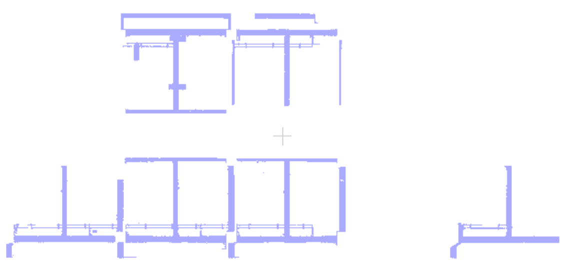

Figure 12. Results after overlay analysis

https://doi.org/10.5194/isprs-archives-XLVIII-3-W2-2022-103-2022

3.2.3 Indoor Door Extraction Experiment

Since the point cloud data is in three-dimensional space and the grid image is a two-dimensional plane, after the point cloud is projected and dimensionally reduced, the "door" will be mapped to a contour surface. This can be reflected in the real world through the upper edge plane of the door frame. It should be noted that the stair plane in the building may interfere with the screening of the door upper edge plane, so the stair plane is manually removed.

As the door component is generally located in the upper middle of the house, it is selected to slice at the position of 2m-2.5m to select the slice with the upper edge of the door. After the point cloud is projected and dimensionally reduced, the "upper edge of the door" will be reflected as a contour surface, as shown in Figure 14. Where the width of the point cloud is large, it is the upper edge of the door. The framed part in Figure 15 is the door component part.

Because there are different components between slicing point clouds with different heights, the point cloud data containing only wall lines and the point cloud data containing door components are overlapped and analyzed. The non overlapping part is the upper edge of the door. The wall line point cloud is used as the seed point for dimension reduction projection. Judge the non coincidence part with the point cloud with door component.

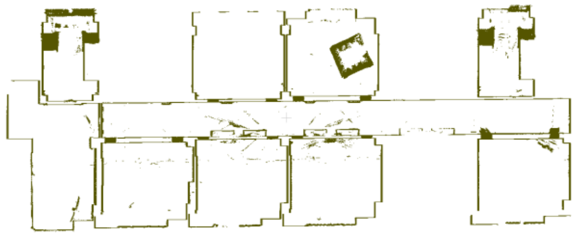

Figure 13. Point cloud data with upper edge information of door

Figure 14. Detail drawing of upper edge of door

3.3 Experimental Analysis

Since there are no beams in the second floor rooms, this indoor beam extraction experiment mainly uses the first floor data. There are eight rooms in the first floor data, but due to the complexity of the staircase area, data extraction was not performed for them. At the same time, the data with smaller plane widths after the regional growth segmentation was lower than the set threshold, resulting in some rooms where the beam information was not extracted. A total of six rooms' beams were extracted for the experiment. The rooms were arranged serially from left to right and from top to bottom. The results are shown in Table 2. From the table, it can be seen that the proposed number of beams basically matches with the actual number of beams. According to picture 15, the beams have clear edges and complete structure, which basically match with the factual beams. As shown in Figure 16, this method can also be extracted for beams with small length.

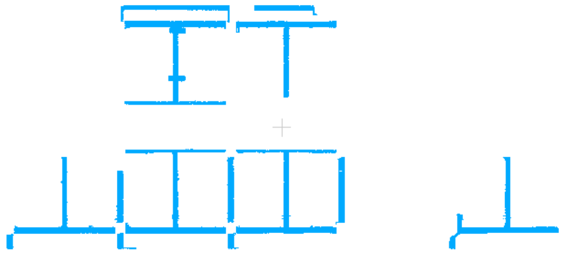

Figure 15 Beam Extraction Results

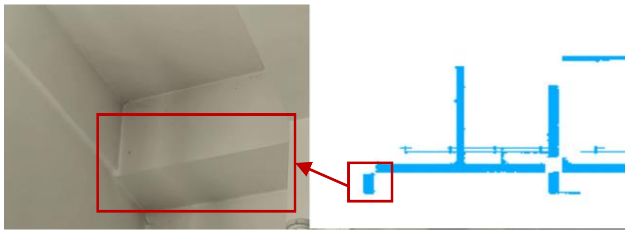

Figure 16. Beam

room number	1	2	3	4	5	6
Number of crossbeams proposed	4	3	4	5	5	4
Actual number of beams	4	4	5	5	5	5

Table 2. Beam extraction results

Table 3 shows the extraction results of the door. Because the door is less affected by noise and has obvious characteristics, the extraction effect of the door is obviously better than that of the beam. In the experiment, the doors of two floors were extracted respectively, and the number of extracted doors is shown in Table 3. It can be seen from the table that the number of doors extracted is consistent with reality. The gate extraction results are shown in Figure 17 and Figure 18. The door data and the wall data are superimposed and displayed, as shown in Figure 19 and Figure 20, the position of the door basically fits the two spaces connected by the door, the contour information is complete, and the position information is consistent with the original information.

floor	1	2
Number of extraction doors	15	12
Actual number of doors	15	12

Table 3. Door Component Extraction Results

Figure 17. First floor doors extraction results

Figure 18. Second floor doors extraction results

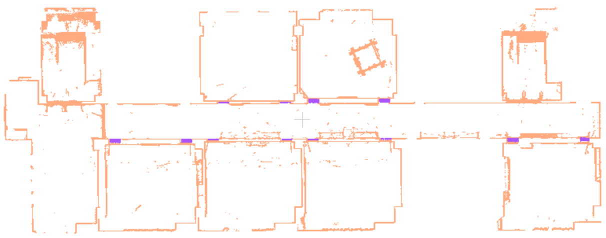

Figure 19. First floor door extraction results

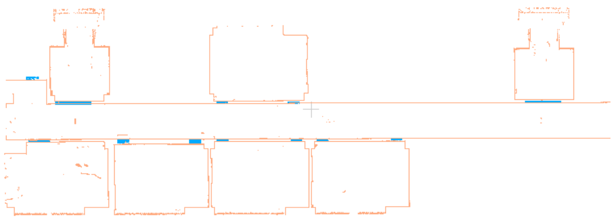

Figure 20. Second floor door extraction results

4. CONCLUSION

For the extraction of closed doors, windows and beams in space, a method of superposition analysis using point cloud slice projections of different heights is proposed. the HS-OA method is able to determine the location of doors by judging the phase difference between the point cloud data with the upper edge plane of the doors and the control point cloud data, and extracting the point cloud data of the upper edge of the doors. The experimental results show that the results of the HS-OA method basically match with the reality. The method in this paper improves the processing speed of the point cloud data,. And the refinement of indoor model opens a new research idea to provide data support for spatial cognition, path planning, and scene display for indoor navigation.

REFERENCES

Fan, Y., 2019. Indoor Space Decomposition and Automatic Method for Indoor Modeling from Laser Point Clouds. *School of Resource and Environmental Sciences*.

Gankhuyag, U., & Han, J.-H., 2021. Automatic BIM Indoor Modelling from Unstructured Point Clouds Using a Convolutional Neural Network. *Intelligent Automation & Soft Computing, 28*, 133-152.

Ji-wei;, Z., De-er;, L., Peng;, Y., Jing-yu;, L., Rui-xue;, L., & Wei-zhen, J., 2020. Window extraction method in dual depth image of point cloud of building facade. *Laser & Infrared, 50*(7), 875-881.

Jianghong, Z., Yan, D., Shuangfeng, W., Mingyue, S., & CHAOYANG, C., 2020. Review of the research progresses on extraction of indoor navigation network. *Science of Surveying and Mapping, 1*(12), 45-54+76.

Le, S., 2019. Door and Window Detection of Indoor Scene Based on "Global-Local' Strategy. *South China University of Technology*.

Lu Weixin, Wan Youchuan, He Peipei, Chen Maolin, Qin Jiaxin, & Siying, W., 2015. Extracting and Plane Segmenting Buildings from Large Scene Point Cloud. *Chinese Journal of Lasers, 42*(9), 0914004.

Oesau, S., Lafarge, F., & Alliez, P., 2014. Indoor scene reconstruction using feature sensitive primitive extraction and graph-cut. *ISPRS Journal of Photogrammetry and Remote Sensing, 90*, 68-82.

Shen Le, Li Guiqing, Xian Chuhua, Jiang Yang, & Yunhui, X., 2019. Door and Window Detection in 3D Point Cloud of Indoor Scenes. *Journal of Computer-Alded Design & Computer Graphics, 31*(9), 1494-1501.

WEI Shuangfeng, LIU Minglei, ZHAO Jianghong, & Shuai, H., 2018. A Survey of Methods for Detecting Indoor Navigation Elements from Point Clouds. *Geomatics and Information Science of Wuhan University, 43*(12), 2003-2011.

ZHAO Bufan, HUA Xianghong, XUAN Wei, CHEN Peng, & Ronghua, Y., 2018. A New Algrithom of Feature Plane Deformation in Point Cloud Based on Threshold Discrimination and Normal Distribution Model. *Journal of Geomatics, 43*(6), 102-105.

Zhao Mengna, Hua Xianghong, Feng Shaoquan, & Bufan., Z., 2020. Information Extraction of Buildings, Doors, and Windows Based on Point Cloud Slices. *Chinese Journal of Lasers, 47*(6), 0604002.

ZHAO Xu, ZHOU Keqin, YAN Li, & Fei, D., 2008. 3D Reconstruction Method for Large Scale Relic Landscape from Laser Point Cloud. *Geomatics and Information Science of Wuhan University, 33*(7), 684-687.