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Automatical Acquisition of Point Clouds of Construction Sites and Its Application in Autonomous Interior Finishing Robot

Wanli Cheng, Hao Shen, Yexi Chen and Xin Jiang*
School of Mechanical Engineering and Automation
Harbin Institute of Technology, Shenzhen
HIT Campus Shenzhen University Town, Shenzhen, China
{*chengwanli,shenhao,chenyexi*}@*stu.hit.edu.cn*

Yunhui Liu
Department of Mechanical Engineering
The Chinese University of Hong Kong
Hong Kong, China
yhliu@mae.cuhk.edu.hk

Abstract— **With the rapid increase of labor costs, it is urgent to use robots to replace part of the manpower in the construction industry. To achieve highly automated interior finishing operations, robots need to be able to sense the sites to be constructed. This paper proposes a solution that allows the robot to autonomously detect the environment to be constructed. And it can also achieve quality inspection and contribute to subsequent planning. The program uses the BIM model of the building as an input and uses the FARO laser scanner as the sensor. The system can automatically select the scan station of the scanner and sequentially move to the selected scan stations to perform scanning, thereby collecting high-accuracy point clouds data at the construction site. The application of the acquired point clouds is also introduced, including the construction quality inspection and the acquisition of house models with accurate dimensional parameters.**

Index Terms— **Interior finishing robot, Point Clouds Segmentation, BIM, Scan planning.**

I. Introduction

The construction industry accounts for a large proportion of the entire economy [1], but at present construction work is still mainly completed by human workers. As labor cost increases and the willingness of young people to engage in construction work declines, people are increasingly aware of the importance of introducing robotics into this field. In recent years, many researchers studied the scheme of applying robots to the construction work. In [2], researchers at the Israel Institute of Technology began to use robots for interior finishing work in the 1990s. They developed a robot called TAMIR for painting and tiling, but the robot could only perform very simple tasks in a structured environment. There are also many other robots similar to the aforementioned ones, they all require professional technicians to write delicate program specified to the task in advance. The need for human intervention prevent these robots from practical employment. In [3], a painting robot called Pictobot is designed for assisting decorator. Pictobot can work with workers to complete wall painting of warehouses. It is equipped with a ToF camera for sensing the construction object. Therefore, autonomous construction work can be completed locally, but human assistance is still necessary to complete the overall construction work. In [4], researchers at the Federal Institute of Technology in Zurich developed the robot dimRob, which is able to build walls with curved shape based on the 3D model of the design. With the information involved in the model, the robot can complete the construction work autonomously.

It can be seen from the literature that with the advancement of technology, the autonomy of robots used in the field of construction finishing work is improving. But due to the complexity of working environment, the autonomy of robots currently achieved for this field is still limited. For example, in the case of wall grinding and putty applying, in order to enable the robot to complete the work autonomously, it needs to know the construction environment. Especially the structural information is important for many subsequent processing like task execution planning. Moreover, before and after construction work, there are also many needs for the robots to automatically inspect the quality.

The work of this paper focuses on the realization of the high-precision building structure acquisition and the quality inspection using laser scanners mounted on a mobile platform. With the development of civil engineering, most of modern buildings adopt BIM (Building Information Modeling) technology in the design stage. We assume that our construction objects have BIM models. However, in the actual construction process, the design parameters in the BIM model cannot be accurately realized. In most cases, the actual completed building layout will have a certain deviation from its design value, so the data in the BIM model cannot be directly used for the purpose of task planning. However, the information involved in BIM can be used by high-precision 3D laser scanners as an aid in obtaining accurate 3D models of the construction site. Given the high-precision 3D point clouds data of the working site, construction task planning for autonomous robot can be realized, and the quality inspection can also be achieved at the same time.

The rest of the paper is organized as follows. In Section II, the method for obtaining 3D cloud data of construction site is described. The details on how to extract house structure information from point cloud data and how to use the extracted structure information are then presented in Section III. This is followed by experimental part in Section IV before we concludes the paper in Section V.

*The corresponding author:Xin Jiang(x.jiang@ieee.org)

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Fig. 1. Laser scanner mounted on a mobile platform.

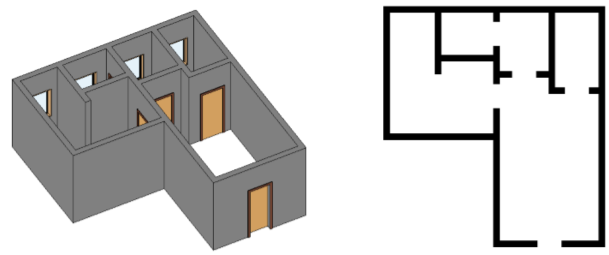
II. Acquisition of 3D point clouds data

In this section, methods for automatically acquiring 3D point cloud data from a construction site will be introduced. A 3D scanner (FARO S70) mounted on a mobile platform (clearpath ridgeback) as shown in Fig. 1 will be used for purpose of point cloud acquiring. On the front side of the mobile platform, a LIDAR(Hokuyo UST-10LX) is installed for localization. The mobile platform is used to simulate a mobile construction inspection robot which can move to different locations with the information of design.

A. BIM based Mobile platform localization

To realize autonomous movement of the mobile platform in the working site, the localization problem of the mobile platform should be solved firstly. In the general task of mobile platforms localization, it is necessary to first remotely move the mobile platform in the target environment and use SLAM technology to build the map. After the map is created, it is then used to complete subsequent navigation tasks. The advantage of this approach is that we can obtain a more accurate map. And at the same time the disadvantage is that it requires large time and effort in map building. Considering our specific scenario of construction work, the existing BIM model of the building can be used to help us complete the positioning and navigation tasks.

BIM is a popular technology in the construction industry. More and more buildings use BIM technology when designing. A large amount of information including the 3D model of the building is embedded in the BIM model. The 3D model in BIM can be converted to an *.ifc* (Industry Foundation Classes) file. We have developed a program that interpret the construction structure information we need from the *.ifc* file. The grid map for laser based localization is extracted from it. This step is used to replace the process of pre-building the map in the general way. Fig. 2 demonstrates the function of the program for map generation. It should be pointed out that due to the existence of errors during construction, there will be errors between the map generated according to the BIM model and that reflecting real situation. However, in the following experiments, we confirmed that with localization of gmapping, the generated map with error can still guarantee precise enough localization.



(a) (b)

Fig. 2. (a) 3D model in BIM, (b) Extracted layout map.

B. The Planning of Scanning Station

The FARO laser scanner needs to be stationary during scanning, and it takes a long time to perform a scan to acquire high-precision point cloud data at one scan station. A scan of a single station takes about six minutes. In order to minimize the time required for the robot to acquire point cloud data, it is necessary to plan the scanning viewpoints before the robot starts the scanning operation. The scanning planing is formulated as the problem of minimizing the scan station number while ensure that the whole space is completely covered without loss.

The aforementioned map generated by the BIM model is used as the basis for the scanning station planning because it contains basic information about the site to be constructed. In the implementation of specific planning tasks, we follow the way people take to arrange the scanning station. First we divide the entire map into multiple individual blocks partitioning the floor into different rooms. And then we adopt a simple and greedy algorithm for each block to complete the scan station placement. After the arrangement of each scanning station is completed, a comprehensive verification is performed to verify whether the entire area to be constructed has be completely covered by the designed scanning station sequence. The process of obtaining the scan station is shown in Fig. 3. The pseudo code of the greedy algorithm is shown in Algorithm 1.

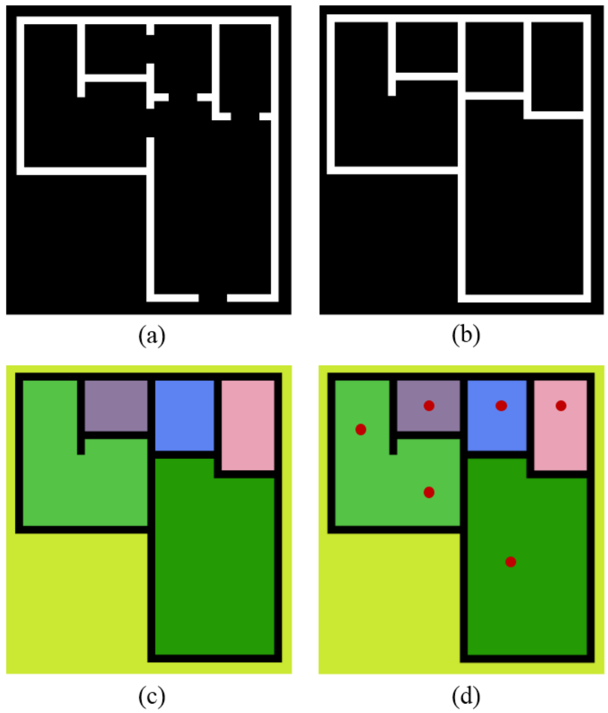


Fig. 3. (a)Original map (b)Closing the part of the door with a "close" operation (c)Seeking connected domain operations, each color represents a room (d)Use a greedy algorithm to obtain station for each domain

Algorithm 1 Scan station planning based on greedy algorithm

Input: Area to be planned
Output: viewpoints

```
Evenly arrange candidate scan stations
Initialize coverage_max, vp
for each candidate scan station do
    Calculate the coverage of scan station
    if coverage >coverage_max then
        coverage_max = coverage
        update vp
return vp
```

C. *Scan station planning in the presence of unpredicted obstacles*

When the construction work is in progress, the site to be constructed may be messy. And there may be some unpredicted obstacles on site, such as the stacked materials. These potential obstacles have little impact on mobile platform navigation, but they have a huge impact on the scanning of scanners. The laser line may be blocked by obstacles unreflected on the map generated from BIM models. It causes occlusion of part of the architectural elements. Therefore, we need to consider the impact of these obstacles on scan station planning. Thus in the presence of unpredicted obstacles, the re-designed scanning station sequence solution should still cover the space that need to be scanned.

The existing SLAM method can easily implement the function of reflecting obstacles to the established navigation map. However, in order to facilitate the matching of point cloud information and BIM model, we need to modify the map according to the actual situation of the construction site based on the map generated by the BIM model. We first let the mobile platform move around the site following the path previously designed with no obstacles assumed. The collected lidar data is analyzed during the movement and is compared with the map. The part considered to be an obstacle is added to the previous map. Fig. 4 shows how to add obstacles to the map generated by BIM. It should be pointed out that in the process of moving, sometimes there may be a large error in the localization of the mobile platform, as shown in Fig. 4(c). So we need to calculate the ratio of the laser data points that fall in the wall area of the map. This ratio can be used to determine the accuracy of the localization. Only retain the data whose ratio is greater than a certain threshold, and omit the data when the location is inaccurate. Then, the scan station planning is re-conducted again based on the updated map.

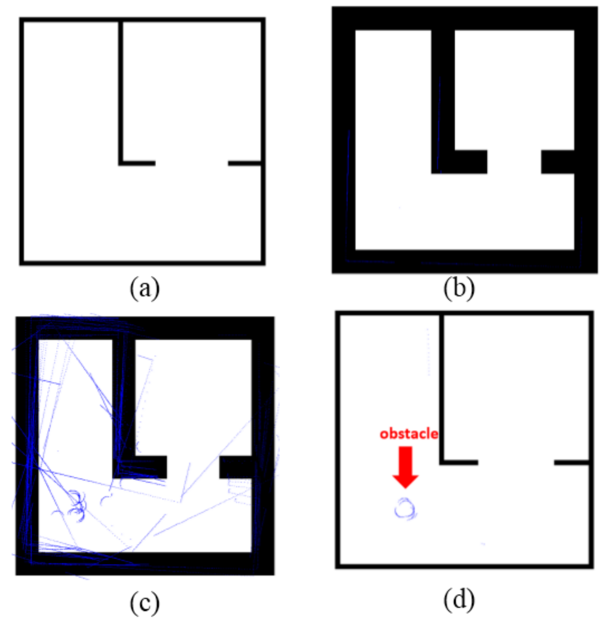


Fig. 4. (a)Original map (b) Corrosion of the map to enlarge the width of the representative walls (c) Point cloud data obtained during moving (partial data is not accurately located) (d)Only obstacles in the data with accurate localization will be recorded

D. *Point cloud data merging*

After the planning of the scan station is completed, the mobile platform will carry the FARO scanner for site-by-site scanning. In each site it will gather 3D point cloud of the surrounding environment. By merging these point cloud data, we can obtain the overall point cloud data of the construction site. The software provided by the FARO scanner can help us complete the merging work. In the future, we plan to realize automatic point cloud merging task, using the prior information about the location of the scanned site.

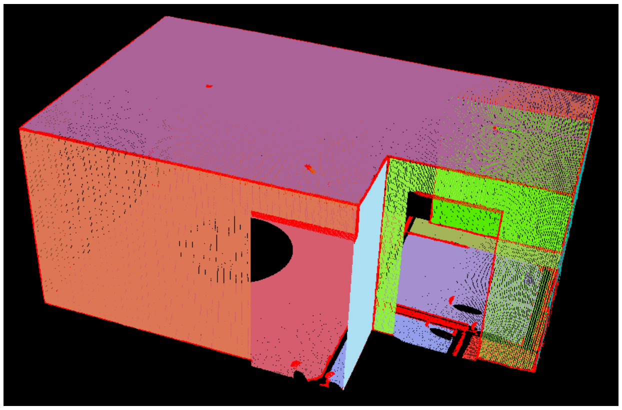


Fig. 5. Extracting planes using region growing algorithm

III. Application of Quality Inspection and Construction Work Planning

In the previous section, we designed methods for obtaining point clouds data of the sites to be constructed using the FARO laser scanner which is installed on the mobile platform. After the point cloud data of the sites to be constructed is obtained, we can realize two types of applications: using point cloud data for quality inspection and task planning of robotized work.

A. Extract wall information from point clouds

The point clouds we obtained contains various elements on the sites, including a variety of architectural elements such as walls, ceilings, floors, beams, columns, and so on. Among them, the most important part is the walls. After extracting the point clouds belonging to each wall, we can analyze the construction quality of the wall. On the other hand, measuring the size of the wall helps us to obtain accurate information on the structural parameters of the building. Therefore, the first thing we need to do is to segment the walls from the overall point cloud and label the point clouds corresponding to each wall.

Since the geometrical features of the wall are planes, we first extract planes from the point clouds data, and the part of the extracted planes represent the walls. We use a region-growth based algorithm which is introduced in [5] to extract the plane. Fig. 5 shows the results of the algorithm.

Through the region growing algorithm, we can obtain the planes in the point cloud well, and these planes correspond to the wall surfaces. In addition, we need to recognize each plane segmented also from design drawing of the building. Thus it is necessary to map the segmented point cloud surface to the wall surface expressed in the BIM model. Algorithm 2 shows how to achieve one-to-one correspondence between two planes.

B. Wall quality inspection

After the point clouds corresponding to the wall is obtained, we can use the point cloud data of the wall to calculate the flatness value of the wall[6]. In addition to the analysis of the relationship between the walls, we can also calculate the size

Algorithm 2 Match the extracted walls to the information in the BIM

Input: Map generated by on BIM, Wall extracted from the point clouds
Output: Correspondence

1. Use the region growing algorithm to obtain the planes in the point clouds and calculate their centroids and normal vectors
2. The centroids and normal vectors of the respective planes are converted to the map coordinate system by using the transformation relationship between the scan station and the map when the scan is performed
3. Obtain the centroid and normal vector of each plane in the BIM model
4. Calculate the deviation between each plane extracted from the point cloud and the parameters of each plane in the BIM. The minimum deviation is determined as the corresponding two planes
5. **return** Correspondence between planes in BIM and planes extracted from point clouds

parameters of the wall. By comparing the dimensional parameters of the wall with the design values in the BIM model, it is possible to determine whether the actual construction dimensions of the wall meet the design requirements.

When measuring the flatness using the point cloud data of the wall, we refer to the measurement principle stated in the related standard. It is followed by construction worker (using a two-meter ruler). We select a part of the point cloud in the wall as a substitute for the measuring surface. We then fit the plane equations of these points and then calculate the maximum deviation of these points to the fitted plane. This value can represent the flatness of the wall.

C. House wireframe extraction

Due to various factors in the actual construction process of the building, there are some deviations between the parameters of the actual building and the BIM model. Therefore, the parameters in the BIM model cannot be directly used as the basis for the construction path planning of the interior finishing robot. Take the wall grinding operation as an example, the interior finishing robot needs to know the real and specific parameters of the required working area to perform the path planning. Directly using the parameters in the BIM model will lead to the wrong planning path. Therefore, it is necessary to use the obtained point cloud data to calculate the real size parameter information of the building, thereby correcting the data of the deviation in the BIM model.

Observing the extracted point cloud of the wall, the extraction effect of the edge part is not good. If the contour is directly extracted from the point cloud data corresponding to a single wall, the accuracy is not high enough[7]. Therefore, we use the intersection line of the wall and its adjacent walls to obtain a high-precision wall contour, and calculate the wall size parameters accordingly. The calculated wall size is the

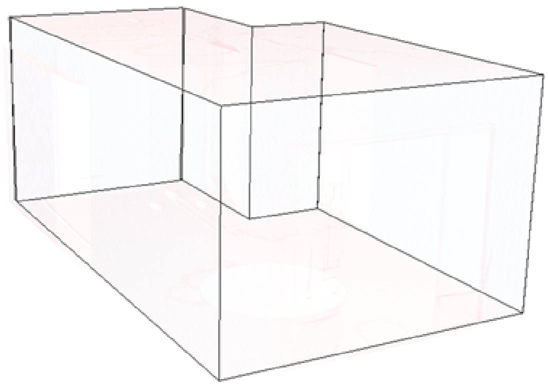


Fig. 6. house wireframe diagram

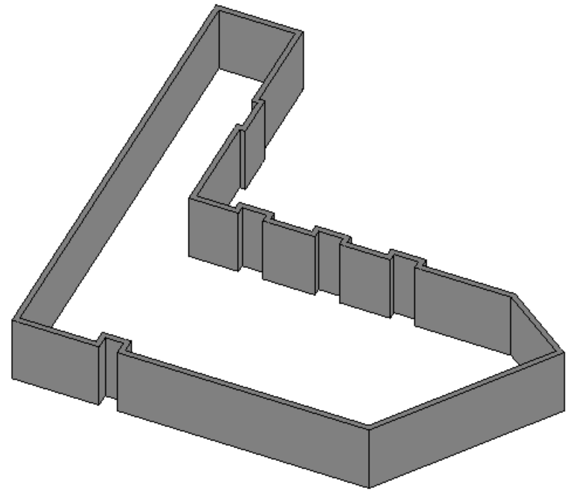


Fig. 7. BIM model of the experimental site

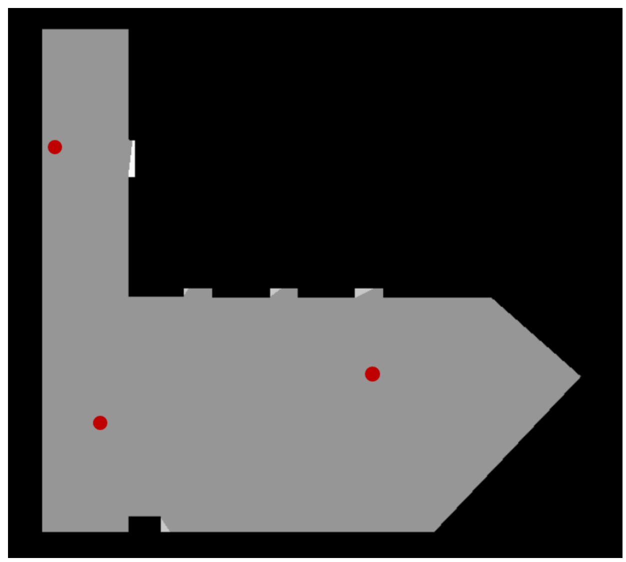


Fig. 8. Planned scan viewpoints (red point in the figure)

actual size of the site to be constructed, and the size parameters can be used to replace the design value in the BIM model. We can also draw a wireframe of the house based on the calculated dimensions. Fig. 6 shows an example of the obtained house wireframe diagram. Since the data in the house wireframe diagram is accurate, we can carry out subsequent specific construction process planning tasks based on this[8].

IV. Experiment

In order to verify the effectiveness of the method described in this paper, we conducted a point cloud acquisition experiment in a space in a teaching building. As shown in Fig. 1, the experiment uses clearpath's ridgeback mobile platform with the FARO S70 laser scanner installed on the mobile platform. The BIM model of the experimental environment is shown in Fig. 7. After experimental verification, using the map generated by the BIM model, the mobile platform can perform positioning and navigation smoothly. The scan is performed according to the planned viewpoints(Fig. 8), and the obtained point cloud data is as shown in Fig. 9

Using another point cloud collected from an actual construction site, we verified the wall flatness analysis and the generation of the wireframe. Select a wall to calculate the flatness using the method in section 3. The calculated result is 1.2mm, which is consistent with the manual measurement, but more tests need to be done to verify the accuracy of the flatness measurement method. The obtained wireframe is shown in Fig. 6.

V. Conclusion

This paper describes how to automatically acquire complete point clouds of sites to be constructed using a laser scanner installed on a mobile platform. And the application of the obtained point clouds in the interior finishing scene is also introduced. Combined with the information provided by the BIM, the device can perform a scanning task according to the automatically generated scan station sequence, thereby obtaining a complete point clouds of the sites. Using the obtained point cloud data, the flatness of the wall can be measured. And a high-precision site model can be obtained, which can be used for the construction planning of a robot that implements a specific construction process. These tasks have a significant impact on improving the autonomy of the interior finishing robot.

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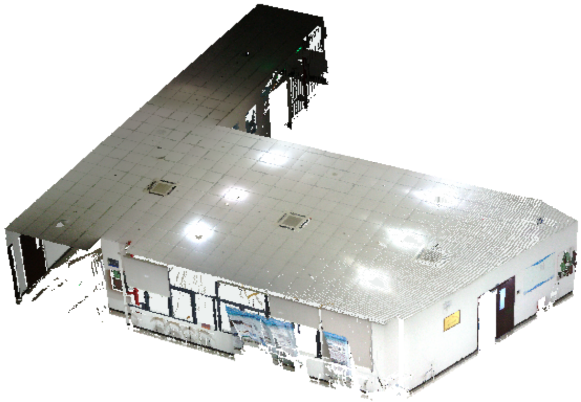

Fig. 9. Obtained point cloud of the experimental site

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