Representative Construction Engineering Drawings Combining SLAM and Ground-Based LiDAR

Chutian Gao¹, Ming Guo¹,²,³, Zexin Fu¹, Dengke Li¹, Xian Ren¹, Mengxi Sun¹, Yuquan Zhou¹ and Peng Cheng¹*

¹ School of Geomatics and Urban Information, Beijing University of Civil Engineering and Architecture, Beijing 102616, China
² Engineering Research Center of Representative Building and Architectural Heritage Database Ministry of Education, Beijing 102616, China
³ Key laboratory of Modern Urban Surveying and Mapping, National Administration of Surveying, Mapping and Geoinformation, Beijing 102616, China
⁴ Beijing Key Laboratory for Architectural Heritage Fine Reconstruction & Health Monitoring, Beijing 102616, China
Email: 835288680@qq.com

Abstract. Obtaining architectural engineering drawings is a crucial aspect of upgrading and repairing structures. Traditional elevation measuring is ineffective and results in a poor rate of restoration. The current building elevation measurement solutions based on 3D scanning technology all obtain building 3D point cloud data from a single type of laser scanner. These two methods can't get both indoor and outdoor scenes at the same time. This paper presents a scanning strategy that combines SLAM with Ground-based LiDAR to solve this problem. The point cloud data for the building's indoor and outdoor scenes are obtained independently, and the Ground-based LiDAR point cloud data is registered locally using the iterative closest point (ICP) algorithm. The SLAM point clouds and the Ground-based LiDAR point clouds are then registered as a whole to develop an overall model of the building using point constrained error equations. For various reasons, the building can be trimmed into a planar point cloud model depending on the application. Finally, engineering drawings for the construction of the building can be drawn. The method's viability was demonstrated by using it in a 3D scanning project of a scenic site in Beijing. This technology improves model information interpretability, scanning efficiency, and provides powerful data assistance for building rehabilitation and repair. It is extremely important in the disciplines of urban planning, rehabilitation, and historic preservation. After performing a more optimal preprocessing, more than 90% classification accuracy was achieved across 18 low-power consumer devices for scenarios in which the in-band features-to-noise ratio (FNR) was very poor.

1. Introduction

Engineering drawings, such as elevation and section drawings, are essential for planning, designing, renovating, and repairing a building. The surveying and mapping industry typically uses total stations to get the coordinates of critical places on a building, and then uses tools to measure the dimensions of the structure. To record the building data, a building sketch is made at the measurement site. Finally, drafting software is used to create the building engineering drawings. This approach is time-consuming and inefficient, with accuracy limited to centimeters.
At present, with the mature development of lidar technology, it began to be applied to the field of building analysis [1], using lidar to obtain the building point cloud data, using the point cloud data to draw the building engineering drawing method is proposed. Wang Guoli et al. proposed a technique for lidar point cloud denoising and applied it to tower deformation analysis [2-3]. Guo Ming et al. realized the automatic generation of an accurate colour point cloud of buildings, which also provided a way of thinking for deformation monitoring of tower buildings [4-6]. The establishment of various types of building models has a lot in common, and their methods are worth referring to the analysis of other types of buildings. Zhang Li et al. obtained point cloud data of outdoor multi-station scenes by a stationary-borne laser scanner and used the iterative nearest point method (ICP) to register point cloud data of different stations [7]. Yuan Lingyun et al. improved the scanning mode based on the traverse method to improve the efficiency and accuracy of point cloud scanning [8]. Ma used a handheld laser scanner to scan the indoor scene [9]; Both Long Runze et al. and Li Zhiyuan et al. used the method of local feature matching to register point cloud data [10-11]. In addition, there are also foreign studies in this direction [12-13], and some scholars put forward that deep learning can be used to build architectural models [14]. The above several methods employ a single type of laser scanner to obtain construction point cloud data, such as using the station load laser radar for outdoor attractions cloud, or according to the portable laser scanner for indoor scene SLAM point cloud, and then through the local geometric feature between two measurement site cloud data for point cloud registration, two failed to both indoor and outdoor scenes. On this basis, this paper proposes a blend of the SLAM and standing load lidar scanning methods, respectively, for indoor location SLAM the laser point cloud data of point cloud and outdoor scene, recently through iteration point method (ICP) to local registration station load lidar point cloud data, and then build a station constraint error equation of SLAM point clouds and complete lidar point cloud registration, Finally, generate the architectural engineering drawings for different needs.

This method integrates the indoor and outdoor scene point cloud model, improves the accuracy of point cloud model and construction engineering drawing, speeds up the measurement efficiency, and increases the selection of generated construction engineering drawings.

2. Registration Principle

In order to obtain the overall model of the point cloud, it is necessary to register the point cloud of multiple stations. The point cloud of the indoor scene is acquired by SLAM, and the point cloud data is written by the SLAM algorithm, which is not discussed in this paper. The outdoor scenic spot clouds obtained by ground-based lidar were first rough registered by the geometric feature matching method and then further reported by the ICP algorithm. Finally, the processed indoor and outdoor point cloud data are registered as a whole to obtain a unified overall point cloud data. Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented.

2.1. Point Cloud Registration for Outdoor Scenes

Outdoor scenic spot clouds were registered twice by geometric feature registration and ICP algorithm. Geometric feature registration directly transforms point clouds through homonymic features in two stations. There are at least three homonymic features between two adjacent stations, including point, line, plane, sphere, cylinder, etc. The outdoor scenic spot cloud is registered with each feature point and feature plane of the building and the point cloud accuracy after registration can reach 3mm. Feature registration calculates spatial conversion parameters according to three different homonymous features and homonymous feature points in other stations $X_0 = (x_0, y_0, z_0), X = (x, y, z)$, the offset $\Delta X(\Delta x, \Delta y, \Delta z)$. The relationship between the two points is as follows:

$$X_0 = RX + \Delta X$$  \hspace{1cm} (1)

The linearized equation is solved as
That is
\[
A = \begin{bmatrix}
0 & -z_0 & -y_0 & a \\
-z_0 & 0 & x_0 & b \\
y_0 & x_0 & 0 & c \\
\end{bmatrix} = 0
\]

The error equation of rotation parameters can be expressed as
\[
V = At - L
\] (3)

ICP algorithm uses iterative operation to get the optimal rotation and translation parameters and has high requirements on the initial position of the point cloud. After feature registration, the difference of point set part is small, and there is a large area of overlap between adjacent stations, which meets the conditions of the ICP algorithm. Second registration can minimize the distance error between corresponding points of two stations. Given two adjoining site clouds, \( P = \{P_i\}_{i=1}^{N_P} \) and \( X = \{X_i\}_{i=1}^{N_X} \), Search the nearest issue \( Y_i \) of each point \( P_i \) in \( P \) within the \( X \) point set to establish the mapping relationship of point pairs. The corresponding point set of \( P = \{P_i\}_{i=1}^{N_P} \) is \( Y = \{Y_i\}_{i=1}^{N_Y} \), and The following formula can be expressed as:
\[
Y = C(P, X)
\] (5)

\( C \) is the coordinate transformation of the corresponding point, iterating until the accuracy is satisfied.

2.2. Overall Point Cloud Registration
In outdoor attractions, cloud data registration is completed, can be indoor and outdoor scenes of point cloud data as two sites cloud data, build some constraint error equation of the "two" to overall point cloud data registration, indoor and outdoor scene of point cloud data according to the constraint relation between them, and integrated into a unified system, creates a point cloud model as a whole. According to the characteristics of buildings, feature points are selected to achieve the cloud registration of each site. The relationship between feature point \( X_{i0}(x_0, y_0, z_0) \) in the scanned object and its observed value \( X_i(x, y, z) \) is as follows:
\[
X_{i0} - (-\lambda RX_i + \Delta X) = 0
\] (6)

Where \( R \) is the rotation matrix of site transformation, \( \Delta X(\Delta x, \Delta y, \Delta z) \) is the translation parameter, generally, in point cloud operation, the scale parameter \( \lambda \) is equal to 1, the Angle parameter of enormous rotation Angle space transformation is usually solved by Rodrigues matrix, which is constructed by antisymmetric matrix \( S \), \( R = (I+S)(I-S)^{-1} \), where \( I \) is the third-order identity matrix.
\[ S = \begin{bmatrix} 0 & -c & -b \\ c & 0 & -a \\ b & a & 0 \end{bmatrix} \]  

(7)

Combined with the Linearization expansion of the Rodrigue matrix, the error equation of point is:

\[ V_1 = A_1 t + BX - L_1 \]  

(8)

\( V_1 \) is the observed residual value; \( A_1 \) is the coefficient matrix related to spatial transformation parameters; \( t \) is the correct number of spatial transformation parameters; \( B \) is the coefficient matrix to be fixed; \( X \) is a positive value to be set; \( L_1 \) is the observed residual.

3. Experiment
In this paper, the proposed method is applied to a 3d scanning project of a scenic area in Beijing to verify the feasibility and accuracy of the way. The scenic area is primarily old buildings in the 1990s, and the internal and external infrastructure conditions of each building are relatively backward. The structural form is mostly brick and concrete structure, and the single facade style of each building is different. The site fluctuates wildly, with one side facing the lake and one side facing the mountain. At present, the old architectural complex urgently needs to be repaired and processed, and architectural engineering drawings such as elevation and plan of each building need to be obtained. The general situation of the scenic spot is shown in figure 1:

![General situation of a scenic spot in Beijing.](image)

According to the field scene, the engineering scheme of surveying and mapping data collection is developed. The outdoor setting was scanned by site-based lidar and registered according to geometric features and the ICP algorithm. The indoor scene data was collected by SLAM, and the registration was automatically completed by a built-in SLAM algorithm. The point clouds of indoor and outdoor scenes were registered as a whole, and then the noise was removed, and the segmentation was processed. Then the plane point cloud model, which can be used for building engineering drawing, can be obtained, and finally, the engineering drawing can be carried out. The project scheme is shown in figure 2:
In this project, the Faro Focus 3D station bore 3D laser scanner was used for 3D scanning of outdoor scene buildings, while the handheld GeoSLAM Zeb-Revo 3D laser scanner was used to obtain point cloud data of the indoor scene. A total of 34 buildings in 4 architectural groups were surveyed and collected, and cloud data of 300 outdoor sites and 46 indoor sites were obtained. The point cloud data collected were registered. As the repair requirement only required the elevation and floor plan of each building, the outdoor scene cloud was written by a single building. Indoor venue cloud is automatically reported by the built-in SLAM algorithm, and the error of outdoor venue cloud is less than 2mm after rough registration and ICP algorithm. The outdoor venue cloud and indoor venue cloud after registration are shown in figure 3:

![Outoor scene point cloud and Indoor scene point cloud](image)

**Figure 3.** Single registration of indoor and outdoor panoramic spot cloud.

The outdoor scene cloud and SLAM after registration were registered as a whole, and the average error of point cloud after overall registration was less than 5mm. The general point cloud is shown in figure 4:

![Global point cloud model](image)

**Figure 4.** Global point cloud model.

The overall point cloud data also contains noise points and abnormal data, which need to be denoised and optimized, including thinning point cloud, reducing noise and deleting strange facts. The overall smoothness of the processed point cloud is further improved compared with the original data, and finally, the 3D model of the building is generated. Figure 5 shows the 3D model of the building after denoising and optimization:
Figure 5. Building 3d model.

The elevation point cloud model, which can be used for building elevation drawing, can be obtained by cutting the three-dimensional model of the building, and then the point cloud model is imported into CAD software to draw the elevation according to the geometric characteristics of the building. The elevation point cloud model and elevation figure are shown in figure 6:

Figure 6. The Building facade point cloud and elevation figure.

4. Discussion
A point cloud registration method combining SLAM and ground-based LiDAR is proposed in this research. SLAM and ground-based LiDAR gather the internal and outside point cloud data of a building in a scenic spot in Beijing, respectively. To create the overall 3D representation of the building, point cloud registration and denoising optimization are performed. The building engineering drawings are created by intercepting the 3D model of the building and generating a planar point cloud model. The practicality of the method presented in this research has been established. This method merges the point cloud models of both indoor and outdoor scenes into one whole. It not only increases the interpretability of building information, but also improves the scanning efficiency and provides more options for the drawing of architectural engineering plans. It provides strong data support for building renovation and repair, which is important for the fields of urban planning and renovation and ancient building conservation.

Acknowledgments
This research was funded by the National Natural Science Foundation of China [grant number 41971350,42171416,52130809]; Beijing Advanced Innovation Centre for Future Urban Design Project [grant number UDC2019031724]; Teacher Support Program for Pyramid Talent Training Project of Beijing University of Civil Engineering and Architecture [grant number JDJQ20200307];

References
[1] Gao C, Wang G L, Wang Y M, et al. 2019 Status and development trend of digital phenotypic monitoring technology for architectural heritage [J] Science of Surveying and Mapping 44 (05) 85-92.
[2] Wang G L, Gao T, Guo M. 2019 Noise filtering of phase 3d ground laser scanning point cloud[J] Bulletin of Surveying and Mapping (S1) 190-194.
[3] Wang G L, Wu G K, Wang Y M, et al. 2018 Monitoring ancient pagoda deformation with multi-source data[J] Journal of Geo-information Science 20 (04) 496-504.
[4] Guo M, Zhou T F, Yan B N, et al. 2020 Automatic generation of hutong orthographic image of laser radar true color point cloud [J] Science of Surveying and Mapping 45 (06) 89-95.
[5] Guo M, Yan B N, Zhou T F, et al. 2020 Application of lidar technology in deformation analysis of Yingxian Wooden Pagoda[J] Journal of Architecture and Civil Engineering 37 (02) 109-117.
[6] Guo M, Sun M X, Pan D, et al. 2020 High-precision detection method for large and complex steel structures based on global registration algorithm and Automatic Point Cloud Generation [J] Measurement 172(prepublish):
[7] Zhang L, Song L. 2019 Application of 3D laser scanning technology in building elevation mapping [J] Bulletin of Surveying and Mapping (09) 152-154.
[8] Yuan L Y, Li H, Li J, et al. 2020 Application of 3D laser scanning technology in building facade lighting design [J] Bulletin of Surveying and Mapping (01) 164-166.
[9] Ma J, Guo H L, Xie K, et al. 2020 Application of handheld 3D laser scanner in flat elevation measurement[J] Bulletin of Surveying and Mapping (S1) 247-250.
[10] Long R Z, Lu M J. 2020 Three-dimensional laser scanning technology for two-dimensional information extraction and plane mapping in renovation of old residential area [J] Bulletin of Surveying and Mapping (09) 127-131.
[11] Li Z Y, Li D G, Wang J, et al. 2021 Fast extraction method of building facade in old city reconstruction[J]. Bulletin of Surveying and Mapping (02) 164-166.
[12] Chen Y M, Liu X Q, et al. 2019 Engineering - Photogrammetric Engineering: Study Data from Nanjing University Update Understanding of Photogrammetric Engineering (Repeated Structure Detection for 3D Reconstruction of Building Facade from Mobile Lidar Data) [J] Journal of Engineering 85 (2) 93-108.
[13] Hao W, Wang Y H, Liang W. 2018 Slice-based building facade reconstruction from 3D point clouds[J] International journal of remote sensing 39 (19-20) 6587-6606.
[14] Chen J D, Yi J S K, Kahoush M, et al. 2020 Point Cloud Scene Completion of Obstructed Building Facades with Generative Adversarial Inpainting [J] Sensors (Basel, Switzerland) 20 (18).