QUALITY EVALUATION OF POINT CLOUD MODEL FOR INTERIOR STRUCTURE OF A COMMON BUILDING

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ABSTRACT

This paper presents a standardized quality criteria to evaluate the 3D point cloud model of the indoor building which is based on point cloud's data accuracy, the prior characteristics of the building and the coincidence errors of the point cloud model. Our assessment framework involves three steps: the point cloud data acquisition, model generation and quality evaluation. In model generation progress, incapacity of scanning the whole building information one time since its multi-storied spatial structure, the building model need to be registered and merged. In evaluation step, taking into account the need of mapping, indoor location and navigation, the establishment of an interior spatial building model requires accurate measurement. Therefore, we adopt data noise analysis to give a judgement. Then, since the geometric characteristics of the building model are varying, the geometric analysis is proposed to evaluate acquisition errors and registration error. Comparative experiments demonstrate our method give integrate, realistic and reliable quality framework for the indoor building point cloud model.

Index Terms— Quality evaluation, Point cloud model, Indoor spatial structure, splicing, 3D laser scanner

1. INTRODUCTION

Due to the increasing demand for accurate and up-to-date 3D spatial maps including interior structure building models4[1], light detection and ranging(LiDAR) data has become a crucial data source for 3D building models. To allow for the need of different applications and scenarios, the 3D point cloud building models should have various levels of details. The forming procedure of the whole building models includes following steps: the point cloud data acquisition from interior building, data pre-processing, point cloud model generation (e.g. splicing and registration) and model reconstruction. The point cloud data model required a more precise and consistent with the authenticity which can be used for the following building model reconstruction. However, in the model formation step, the acquisition and splicing process may have an impact on the point cloud model. Moreover, a better point cloud building model can be produced for a specific purpose, for instance, Urban planning, building safety assessment and analyzing solar potential from roof directions etc. Since point cloud models are important, apparently, a quality criteria for point cloud models should be announced which can evaluate the integrity of the point cloud model and the accuracy of the data objectively and reliably.

In contrast to the mature image quality evaluation, the quality evaluation of three-dimensional point cloud is mainly concentrated on the data accuracy and positioning accuracy. Zhang[2] made a subjective evaluation of the 3D point cloud model after down-sampling based on the statistical man-made scoring. In terms of the stitching and registration of the model, Razlaw et al.[3]compared the different scenarios and effects of the registration algorithm in map quality and pose accuracy. In[4], the Monte Carlo method was used for assess the quality performance of registration algorithm. In point cloud data quality aspect, Huang[5] proposed an automatic assessment criterion to evaluate the quality of indoor point cloud data by comparing the feature of point cloud data. A deviation analysis between the building models and point cloud data was used to assess the reconstruction models. Ayman's team made a quality control to segment point cloud by analyzing of image and airborne laser data[6][7] .

The purpose of this paper is to establish a systematic evaluation framework for interior point cloud building model, and to carry out quality control of the integrated indoor point cloud. Firstly, we scan the interior of the building structure through different equipment, and then extract the features of the overlapping regions of the point cloud for registration and aligning. After that, the generated point cloud model is evaluated globally. Then, as the error of the acquisition process will result in the loss of point clouds and noise pollution, planes of the point cloud are extracted to verify the data accuracy. The geometric characteristics of the model, the surface structure and line features of the point cloud after stitching are also The geometric characteristics of the model are investigated according to the prior knowledge of the building. In this paper, we present an integrated indoor point cloud assessment framework including the original point cloud data accuracy, the point cloud splicing effect and the complete point cloud model quality.

The paper is organized as follows: Section 2 briefly introduces generation procedure of the interior building structure point cloud model and presents our evaluation method. In section 3 we demonstrates the experimental results, and section 4 concludes our paper.

2. METHODOLOGY

As discussed before, a systematic approach to quality assessment involves a series of steps including the construction of point cloud models and quality control. Fig.1 shows the specific technical details of the quality evaluation method. The performance of the framework can be used to detect the point cloud scanning effect of the mapping system and to analyze the realism of the point cloud model

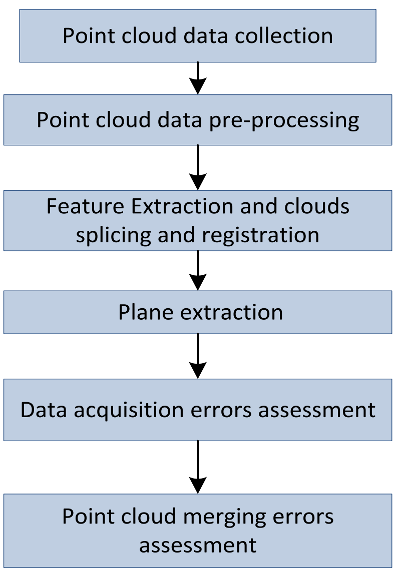


Fig.1. The procedure quality evaluation Framework for Point Cloud model

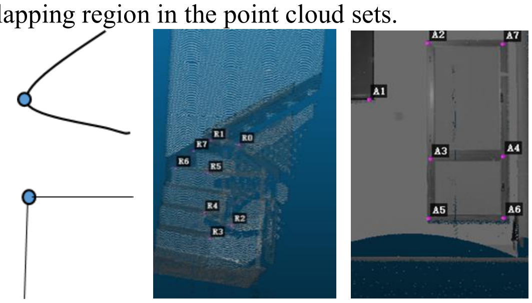
2.1 Point cloud Data acquisition and pre-processing

In this paper, two laser scanning systems are used to obtain 3D point cloud data. One is a Terrestrial Laser Scanner (TLS), scanning at multiple observation points, the other is a Mobile Terrestrial Laser Scanner (MTLS) which based on the SLAM technique of the backpack-type mobile mapping system. Compared to the former, the mobile system performs high efficiency in exploring the environment while achieve a 2D trajectory and building maps. But the mobile system can accumulate errors which means the accuracy is poor. It can be seen in Fig.4 that the raw data are difficult to reflect the structure of indoor building space.

To reduce the unnecessary calculation and scattered point cloud interference, we have applied filters to remove single-point and exploited two down- sampling techniques separately, the octree filter and the voxel grid filter method. Octree is based on the octree structure of the neighborhood search, while voxel grid filter down-samples the point cloud by computing a spatial average of the points in the original point. They both can preserve the original distribution of the point cloud better, and remove redundant points to solve the influence of noise points on subsequent step.

2.2 Point clouds registration and splicing

The key to aligning is to find the corresponding points from the overlapping regions in different point clouds. Although some registration methods including 4PCS[8], Coherent Point Drift(CPD)[9], Go-ICP[10] does not require extraction of point cloud features. However, the significant features such as spin image, SIFT, shape context are beneficial to point cloud sets registration and quality analysis. Different feature descriptors can reflect the relationship between points and points and the geometric characteristics of points. Usually, Feature-based point cloud splicing has the following ways. Point feature-based matching including VPF and FHPF, line feature-based matching and the method based on geometric features e.g. curvatures and Principal Component Analysis (PCA). In this paper, the corner features of the point cloud sets are obtained by combining FPFH describer with the cru-cual point of curvature. As shown in the Fig.2, the selected part is the corner feature description of the overlapping region in the point cloud sets.



(a) (b) (c)

Fig.2. (a) ordinary corner feature, (b) and (c) are the different corner features extracted from point cloud sets

After rotation and translation, we minimize the RMS error of the target function through point to point the ICP algorithm

2.3 Data collection errors

2.3.1 Data noise Analysis

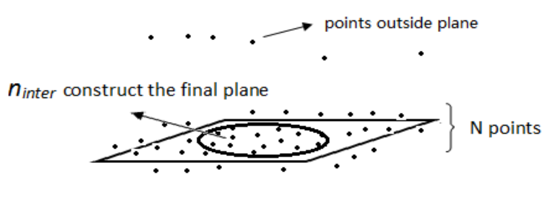
Generally, Laser canning data may produce various errors that are not consistent with the actual situation. Since the laser echo, speed changes and post-shift offset error could degrade the quality of point cloud data especially utilizing moving measurement system, closed-loop detection is used to correct movement trajectory. However, with the noise contamination, the actual data accuracy cannot be verified.

In a realistic environment, the laser scanner data reflected from a smooth wall should be able to form a plane without thickness while the measurement error result in the plane thickness. In this paper, the Random Sample Consensus method(RANSAC) is adopted for extracting the point cloud plane. Then, the data noise is analyzed by computing the average distance from inter-points to the plane. The plane has the highest probability of all candidate ones. Given N points are the number of points in the plane, which means the distance between the plane and the points can be tolerant. Here we define this distance as *dt*. The candidate plane can be constructed by some points under the *dt*. We also define n_{inter} as the final plane candidate points. In Eq.1, we address a quality measurement based on the ratio of points inside the final plane (n_{inter}) to all points (N). In Eq.2, the average distance is discussed by calculating the cumulative mean of the distances from all the candidate points to the plane. Eq3 represents the plane extracted by our methods, which has (A,B,C) vector as the normal vector of the plane. The reason we use the average value is in case of the large number of points. The Fig.3 gives the illustration on the analysis of data noise.

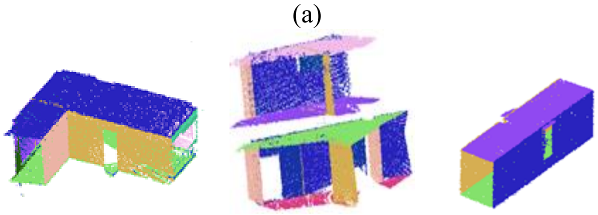
$$Q_{\text{inter-points}} = \frac{n_i}{N} \tag{1}$$

$$dt = \sum_{i=1}^{N} d_i / N \tag{2}$$

$$Ax + By + Cz + d = 0 \tag{3}$$



(a)



(b) (1) Corner (2) Two floors (3)Corridor

Fig.3 (a)The illustration of deciding plane points, (b)Plane extraction works well in different indoor structures with our testing environment

2.3.2 Geometric Characteristics Analysis

The geometric characteristics of the building can give an intuitive visual impact to individuals. For various reasons, for example, inappropriate maintenance and improper operation may cause the laser scanner inaccurately, resulting in forming unusual geometry details.

A building wall is vertical to the ground from our prior knowledge of building structure. This implies the angle between wall and ground can reflects the deviation of the point cloud data. In the previous step, we extracted the plane structure of the building interior. Eq.3 is applied to get the normal vector of a plane and Eq.4 is computed to measure the angle between a wall and a ground. After that, Eq.5 is formulated to evaluate this geometric feature. The Q_{angle} is closer to 1, the better data quality is.

$$\cos\phi = \frac{(A1A2+B1B2+C1C2)/}{[\sqrt{(A1^2+B1^2+C1^2)}\,\sqrt{(A1^2+B1^2+C1^2)})} \tag{4}$$

$$Q_{angle} = \frac{|\alpha - \frac{\pi}{2}|}{\pi/2} \tag{5}$$

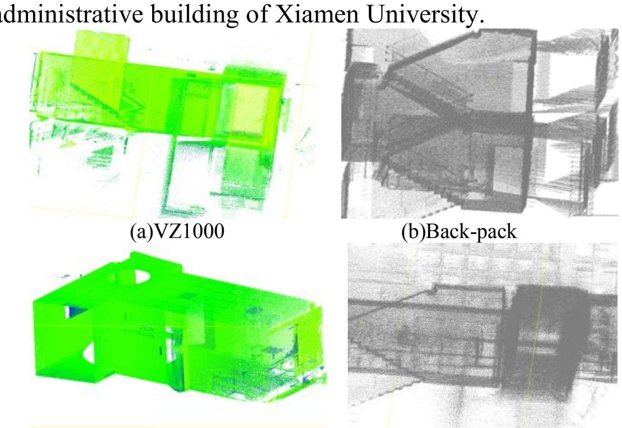
(A1,B1,C1) and (A2,B2,C2) are the normal vectors of two planes respectively. Where α is the angle of the two planes and Q_{angle} represents the deviation from the actual situation.

2.3 Point cloud Merging and registration errors

By analyzing the deviation in the splicing and registration step, we can estimate the quality of point cloud model. However, the errors are not constrained in the overlapping region which means it can be observed in the whole point cloud model. Considering the spatial characteristics of buildings, the gap between two floors and floor height are often regarded as important parameters of indoor building measurement. Similar to the above step, the angle of the floor planes can be calculated by the normal vector of the plane. Two planes stay parallel if we get the same value of angle.

3. EXPERIMENTS AND RESULTS

In this paper, our quality evaluation method was tested on Terrestrial Laser Scanner system and mobile Terrestrial Laser Scanner system and three devices are used: VZ1000(TLS), Back-pack mapping system (MTLS) self-developed by Xiamen University and another backpack system developed by HaiDongQingQing. The testing environment is in HaiYun administrative building of Xiamen University.



(a)VZ1000 (b)Back-pack

(c)VZ1000 (d)Back-pack

Fig.4 The original data obtained by different devices

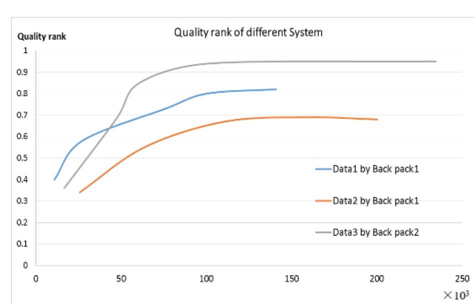


Fig.5 The relationship between point quantity and quality rank

Table1. Planes extracted by our method from different data collectors

	Typical planes	Threshold (m)	Inliers	Outliers	Mean distance(m)	Ground Truth distance (m)
Back-pack1(first collection)	Plane1	0.04	19803	496	0.0914	0.008
	Plane2	0.04	21237	532	0.0996	0.01
Back-pack1(second)	Plane1	0.04	23581	1798	0.0202	0.008
	Plane2	0.04	30152	2073	0.0221	0.01
Back-pack2	Plane1	0.02	93212	4367	0.0127	0.008
	Plane2	0.02	101123	4983	0.0139	0.01

Table2. A typical Structure evaluated by our method

	Collectors	Planes (numbers)	two floor' angle (0< α < π /2)	Wall and ground angle(0<α<π/2)	$Q_{inter-points}$	Q_{angle}	Quality rank
corridor	Backpack1	5	0.088	1.476	0.746	0.940	0.824
	Backpack2	4	0.134	1.512	0.903	0.962	0.917
	Vz1000	4	0.037	1.568	0.945	0.998	0.965

The Planes used for measurement in **Table1** are extracted by our method, which have the similar size in the same scenes. The threshold represents the tolerable error in the plane noise analysis, where the points within the error are taken as the inliers. Table2 demonstrates the quality rank based on our criterion.

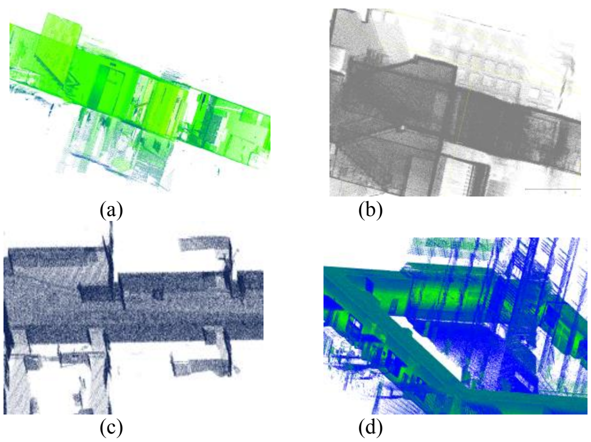


Fig. 6 Different quality levels of Point cloud model

The Figure 4 shows the raw data coming from the different devices. It is obvious that the data quality are rough and the data accuracy are distinct. Figure 5 illustrates that the quality level increases with the increase of the points within a certain number of points. As seen in Figure6, the point cloud model was generated after data processing. The paper here only address the part of buildings. Using our evaluation method, the point cloud model with indoor spatial structure can be judged into different quality levels. After all the quality supervision, Fig.6(d) make the highest level in quality. We conclude that our quality assessment performs well in different scenarios.

4. CONCLUSION

In this paper, we proposed a global quality assessment method for point cloud model in interior building structure. After point cloud data processing and evaluation, the model errors can be quantified to values. We use different approach like point cloud data noise analysis, geometric characteristics analysis and registration error analysis to divide the different point cloud model into different levels of quality by computing the quality ranks.

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