Digital Modeling and Display of Ancient Architecture Based on Multi-Station Laser Scanning

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Abstract. In order to better display and protect ancient Chinese architecture, a three-dimensional model reconstruction method based on multi-station laser scanning is proposed. This method mainly includes several steps, such as point cloud data collection, preconditioning, multi-site cloud data fusion, point cloud data compression, 3D model reconstruction and texture mapping, environment rendering, video processing, and 3D roaming. According to the requirement of video rendering and virtual roaming, we focus on cloud processing, 3D modeling and 3D model display in this paper. Experimental results show that an famous building named Enshi Dong Drum Tower is well digitally reconstructed, so as to result in ethnic characteristics and cultural heritage protection in practical application.

1. Introduction

The digital protection of ancient architectural relics with ethnic characteristics is a hot studying topic in the current cultural heritage and computer field. The scientific issue of protecting and inheriting cultural relics by using digital technology and visualization technology has been paid more and more attention. However, with the development of modern and tourism industry, and impacted by local natural calamities, existent historical buildings have been gradually destroyed or even ruined [1]. The 3D laser scanning technology originated in the late 1960s. Many high-tech companies in the United States and Germany applied it to the 3D model constructing with specific targets, and proposed many new measurement principles and methods [2]. The 3D laser scanning technology can acquire the 3D point cloud data of the building surface conveniently and accurately, prevent different degrees of damage or destruction effectively in the process of cultural heritage digitizing. It is a prosperous technology in material heritage digitization and information service and widely used in 3D modeling engineering [3]. The more commonly used cultural relics display technology currently is mainly cultural relics digital display based on virtual models, which shows the connotation from the aspects of form and texture mainly by reconstructing the realistic cultural relic virtualization model. The 3D laser scanning technology was used to scan the historical hall of Hamburg Municipality, and built the 3D model with the use of point cloud data [4]. The 3D laser scanning technology and infrared camera were used to 3D scanning and ancient building modeling to the churches and monasteries located in Cosenza [5]. And have a comparative study of traditional heritage recording method, photogrammetry and 3D laser scanning [6]. The Canadian Research Center developed a set of high-precision 3D scanning digital system and made a 3D digital reconstruction of the Virgin Mary and the Infant in conjunction with Padova University [7]. In 2009, Brown Nick and Laing Richard applied 3D laser scanning technology to ancient building surveying and mapping [8]. In 2015, Emmanuel Moissan and others used laser...
scanning and sonar to measure a canal bridge, the scanner collected the point cloud of river-filled concrete bridge tunnel structure, the sonar detects the bottom of the river. Then had these two kinds data fused, and finally established complete digital model of the canal tunnel[9]. The State Key Laboratory of CAD & CG of Zhejiang University carried out digital protection and reconstruction of Dunhuang Mogao Grottoes and achieved many research results[10]. Peking University carried out the digital reconstruction of Longmen Grottoes and developed three-dimensional model reconstruction to parts of the relics[11].

This paper is based on the 3D reconstruction digital protection of Chinese Dong Drum Tower. The whole scan is divided into eight stations according to the characteristics of the Drum Tower and its surrounding environment. First, use laser scanning technology to acquire point cloud data with high density. Then get the initial point cloud data fused, model meshed, surface fitted and other series of process to build its 3D model. And carry out texture mapping to the 3D model in conjunction with large size high-definition image data. Last, use a virtual roaming platform to get digital display of extant ancient buildings.

The contribution of our paper is summarized as follows:

1. Take advantage of 3D laser scanning technology to do data collection of multi-base station and multi-resolution on the original building, maximize the accuracy of the building itself by acquiring complete point cloud of the Drum Tower through data registration fusion. The data it collects can be more comprehensive compared to the traditional collecting method and secondary contact with the building site can be avoid at the same time;

2. The essential issues such as point cloud stitching fusion, model meshing and surface fitting are solved due to the multi-resolution 3D model reconstruction scheme based on point cloud and position coordinates;

3. Carry out subsequent model reconstruction and texture processing by 3D software, and optimize the model mapping to make it more realistic thus reproducing the original appearance of the Dong Drum Tower accurately.

2. Our methodology
The specific work process of the work is shown in Figure 1.

![Figure 1. The 3D model reconstruction process of Chinese Dong Drum Tower.](image)
2.1 3D laser scanning
The 3D laser scanner can perform laser measurement on the entire surface of the object, and the data it scanned is called point cloud data, which can be input into the computer directly and construct various geometric data such as points, lines, faces and bodies of the 3D model quickly.

The 3D laser scanner emits a beam of laser signal through the laser emitter, the laser is reflected to the receiver of the 3D laser after illuminating the surface of the object. Then, the spatial three-dimensional coordinates of the target point P can be calculated by the three parameters of the distance S between target point P and the scanner distance S, the azimuth angle α and the height angle β.

The Chinese Dong Drum Tower is a complicated large-size scene. This paper carries out multi-station laser scanning to obtain the complete scene of the Drum Tower. We did data collection before scanning and conducted on-site inspection to get aware of the structure of the Drum Tower. The data collection was developed with the 3D laser scanner from FARO and Canon D700 camera. The process of acquiring point cloud data by 3D scanning is shown in Figure 2.

![Figure 2. The point cloud data acquisition process of Drum Tower scanning.](image)

2.2 Preprocessing of point cloud data

By multi-station laser scanning technology to get the initial point cloud data of the relics of the site. There were noise points due to trees and tourists walking around the sight spot during data collecting. Bilateral filtering was performed on each site cloud data first and then constantly corrected less noise by moving the noise point along the normal direction of the point. The principle of bilateral filtering of point cloud data is shown in formula (1).

\[
\begin{align*}
\hat{p}_i &= p_i + \sum_{p_j \in S_i(p_i)} W_c(p_i, p_j) W_s(p_i, p_j) (p_i - p_j) \cdot n_j \\
n_i &= \sqrt{\sum_{p_j \in S_i(p_i)} W_c(p_i, p_j) W_s(p_i, p_j) (p_i - p_j) \cdot (p_i - p_j)} \\
p_i^* &= \left\| p_i - p_j \right\|
\end{align*}
\]

(1)

\(p_i\) is the noise point cloud, \(p_i^*\) is the filtered point cloud, \(W_c(\bullet)\) is a Gaussian kernel function that controls the smoothness of \(p_i\) and its neighborhood \(p_j\) as standard deviations, \(W_s(\bullet)\) is a Gaussian kernel function with the degree of control feature retention of \(p_i\) and its neighborhood \(p_j\) as standard deviation, \(n_i(n_j)\) is the normal vector of the point cloud \(p(p_j)\), \(\langle \bullet, \bullet \rangle\) is the inner product of the vector.

Scanning data obtained by different station scanner are independent coordinate systems due to different positions thus 3D model cannot be constructed and point cloud data of each station needs to be registered to a unified coordinate system through point cloud splicing. In this paper, the initial splicing of denoised single-site cloud data is completed by geometric features, then use ICP algorithm to perform precise splicing and fusion to the initially spliced data, and finally form the complete site relic point cloud data. Assume that the point cloud data of the two sites is represented by \(P\) and \(Q\), and the transformation between the two point clouds is \(R\) (rotation transformation) and \(t\) (translation transformation), the rigid body transformations \(R\) and \(t\) for optimal registration are described as minimizing the mean square error, as shown in formula (2). The ICP algorithm uses the least squares iterative optimization algorithm to calculate the optimal registration of rigid body transformations in two-site cloud data.
High-density stitching and blending point cloud data can maximize the texture details of the reconstructed model, but high processing power of the computer is required. On the premise of ensuring the quality of the reconstructed model, the point cloud data dilution method based on curvature sampling is used to fine the number of point clouds in the simple bit volume\cite{14}, and reduce the density of point cloud data thus increasing the speed of point cloud processing. Extract the point cloud boundary from the point cloud coordinates, estimate the curvature of all point clouds, and estimate the point cloud curvature threshold and curvature extremes. Determine the reduced distance of the current point based on the curvature of the current point cloud and its nearest neighbor point, thereby calculating the reduced distance of the entire point cloud data. Finally, by traversing the entire point cloud, the larger the curvature change corresponds to the smaller reduced distance, and the smaller the curvature change corresponds to the larger reduced distance, thereby realizing the dilution of the point cloud data.

2.3 Reconstruction of 3D model

Use the surface warp-based method to mesh the streamlined point cloud dataset to build a three-dimensional gridded model of ancient architectural artifacts. The warp-based point cloud data triangulation method uses the deformed hyperquadric surface to perform surface fitting on the point cloud dataset, which achieves a better approximate matching between the surface and the input point cloud dataset. During the surface fitting process, the closer the distance of the discrete point cloud data to the hyperquadric surface, the higher the accuracy of the triangulated model. Since the three-dimensional model hole phenomenon exists in the process of triangulation of point cloud data, identify the holes existing in the triangulated model by human interaction, and use the priority pre-order grid technology (AFM)\cite{15} to establish a hole initialization matching grid. Then calculate the new coordinates of all the vertices in the matching mesh by solving the Poisson equation, the filling of the mesh holes is realized after many iterations.

Surface fitting of the repaired 3D mesh of ancient architectural artifacts by NURBS surface fitting method\cite{16} to realize the 3D surface reconstruction of ancient architectural relics model. The NUBRS surface fitting method is to derive the control vertices and corresponding weights of the surface by using the least squares non-uniform B-spline according to the model 3D mesh having the topological structure\cite{17}, thereby obtaining the horizontal and vertical curved surfaces of the ancient architectural artifact model. Parametric equation.

3. Experiments

3.1 Point cloud based acquisition, splicing, denoising

Import the point cloud data obtained by laser scanning into the computer, the scanned single-site cloud is as shown in Figure 3. Then denoise the initial point cloud to reduce the amount of data and get more accurate point cloud data, and the result is as shown in Figure 4. Add a single scanning site, then pair the point cloud, create a splicing group and splicing in turn. The view of the Drum Tower splicing is as shown in Figure 5.

Figure 3. Scanned single-site cloud map.
3.2 3D virtual reconstruction based on point cloud data

After a series of processes to the point cloud of Dong Drum Tower, the triangular mesh of the Drum Tower was obtained by having the point cloud packaged. The reconstructed model diagram is as shown in Figure 6.

![Figure 4: Point cloud map denoising comparison.](image)

![Figure 5: Rendering of splicing point cloud.](image)

![Figure 6: Reconstructed model diagram.](image)

Import the initial model into Maya, the 3D modeling software, for fine modeling and UV processing, carry out texture creation and texture output by Mudbox, and finally complete the environment rendering through Lumin. Rendered video can be exported by AfterEffects afterwards as the effect shown in Figure 7, or have virtual roaming display through Unity 3D like Figure 8.

![Figure 7: Front](image)

![Figure 8: Front](image)
Figure 7. Rendering of 3D model reconstruction.

Figure 8. Rendering of virtual roaming display based on Unity3D.

4. Conclusion and future work
In this paper, 3D model reconstruction process and method based on multi-station laser scanning is proposed aimed at the digital display of ancient architecture, which includes point cloud data collection, preconditioning, multi-site cloud data fusion, point cloud data compression, 3D model reconstruction and texture mapping, environment rendering, video processing, and 3D roaming to achieve the entire process. The Chinese Dong Drum Tower with ethnic characteristics and cultural heritage value was reconstructed according to the scene virtualization method, providing a reference for the point clouds acquisition of the same type of ancient architecture.

Acknowledgement
This work was supported by National Natural Science Foundation National Natural Science Foundation of China under Grants, funded by 61562025; Hubei technical innovation special project (key project) of China under Grant, funded by 2018AKB035; Hubei Chengguang Talented Youth Development Foundation (HBCG).
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