Real 3D Digital Method for Large-Scale Cultural Heritage Sites

1st Shao-xing HU, 2nd Hong-bin ZHA, 3rd Ai-wu ZHANG
1st School of Mechanical Engineering & Automation, Beijing University of Aeronautics and Astronautics, Beijing 100083, 2nd National Laboratory on Machine Perception, Peking University, Beijing 100871, 3rd Ministry of Education Key Lab on 3D Information Acquisition & Application, Capital Normal University, Beijing 100037
{husx@buaa.edu.cn, zhangaw163@163.com}

Abstract

Digital preservation of cultural heritage sites has become a global problem. The paper proposes a real 3D digital method for culture heritage sites using 3D laser scanners and CCD cameras. Firstly, we preprocess the laser scans for noise removal and hole filling. Next step is using an improved ICP algorithm we present step-by-step registration to align all range scans into a common coordinate system. And then, we proposed a filtering of 3D data compression and use a volumetric-based algorithm for the construction of a coherent 3D mesh that encloses all range scans. Finally, through texture mapping, we obtain real 3D and real texture models. The example of the construction of the 3D model of buildings and grottos are presented.

Keywords---**Cultural Heritage Sites; Digitization; Laser scan; 3D model; Camera calibration; Texture mapping.**

1. Introduction

Cultural heritage sites show the development process of a nationality on economy and culture. However, with the lapse of time and the effects of human activities, cultural heritage sites are subjecting to erosion and vandalism. How use new techniques to protect cultural heritage sites has become a global problem.

Over the past decade years people finished many works for protecting cultural heritage sites. For example, Dunhuang Academy China developed a computer restoration and exhibition system of cultural relics information[1]. It used image processing and digital photogrammetry to recode the information of murals and cultural relics. Zhejing University of China researched the project: Fuse of multimedia and intelligent technology and artistic restoration[2]. The two projects main employed image processing and virtual reality.

In fact, the textured 3D models are more important for preservation of cultural heritage because they can provide geometric and textured information for conversation and restoration of culture heritage sites. So fast capturing geometric data and textured data and modeling become new research focuses. Some notable projects have appeared in succession, including the modeling of Michelangeo's Daivd and other statues[3], the Pieta project[4], the Great Buddha project[5], and the virtualization of Byzantine Crypt[6].

Our goal is using real 3D data and real texture data to creating 3D models of large-scale cultural heritage sites. Our method overlaps the work of the above researches, but differ in several ways. First, our target objects are large-scale objects. Second, we can't use a laser range finder and a structured-light range finder to measure our targets because our targets are larger than the usual targets for these sensors.

Our main work include: 1) Use a time-of-flight laser scanner (Cyrax 2500) to capture geometry data and use high-resolution digital camera to obtain texture data. 2) Preprocess the laser scans for noise removal and hole filling. 3) Present step-by-step registration of multi range scans. 4) Create geometric models. 5) Realize texture mapping.

2. 3D data preprocessing

Generally, when measuring cultural heritage sites, each range scan includes some objects such as cars, traffic lights, people, trees, etc. that occlude the actual measured object. Objects of this type have the following two properties:

1. They lie on the front the large structures we measure, and they constitute unorganized point sets if we compare them with the regular structures we measure.

2. They lie on the back the large structures we measure, and they are small in size if they are compared with the measured large structures.

Our goal is to only retain the data that confidently substitute the actual measured object. We make some assumptions that are similar to the one proposed in [17]: 1) the measured large structures are usually vertical, 2) extend a small range in horizontal direction for measured the large structures, 3) z-axis of laser scanner keeps perpendicular to the ground plane, x-axis and y-axis keep parallel with the ground plane. In cylinder coordinate system, the vertical structures keep vertical. For each scan line, these points on the same vertical structure have a same distance to the scanner, we define the main range as the range value that occurs most frequently, the measured large structures and other vertical objects such as a street light or a tree trunk are extracted. With the second assumption and the location of the measured large structures, we filter out the latter class of vertical objects. Figure 1 shows the process of scanline segmentation.

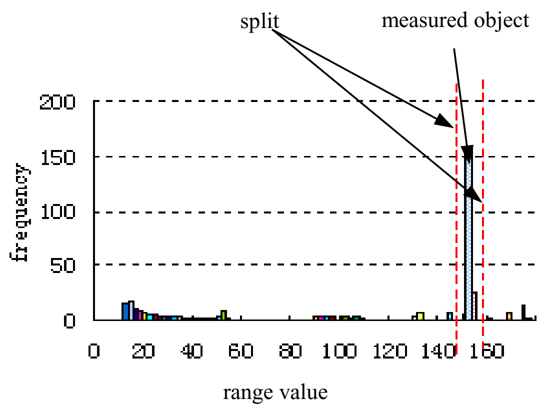


Figure 1 The Process of Scanline Segmentation

After extracting the measured structures, we will find some holes on them sometimes. Holes are created due to the following reasons:

1. Occlusion from other scene objects (i.e. trees, cars, etc.). The removal of these objects generates holes.

2. Glass windows. The laser beams pass through the glass and measure points in the interior of the buildings (ceilings, bookcases, etc.)

We employ two approaches to fill holes:

1. If the hole is on a planar region, we employ linear interpolation, for example, windows.

2. If the hole is on a no-planar region, we employ quadratic surface interpolation, i.e. sculpture.

3. Registration of range scans

To acquire data describing an entire structure requires capturing multiple range scans from different locations and registering them together correctly. The strategies of registration have main two types: one is point-based registration [7]; the other is feature-based registration [8,9,10]. Because extracting features from cultural heritage sites is very difficult, we select point-based registration strategy.

Point-based registration demands to search correspon-ding points between two overlapping scans. Zhang et al. proposed fast global registration of multiple 3D data sets from outdoor large scenes [11]. She employed two attributes of laser sample point: position and reflectance to search corresponding points between two overlapping scans by mahalanobis distance, and use reverse projection to speed up searching corresponding points.

We employ the method of Zhang et al. to register range scans by step-by-step way. First, we divide the two range images into N and M child images, and suppose the child images from different range images include equal pixels. We compute the similar degree of the two child images from different range images by mahalanobis distance. We select three pairs of child images that they have maximal similar degree and compute their centers. We use the three pairs of centers to create an initial estimate.

When using laser scanner to measure objects, we can obtain a range image and a reflectance image, and reflectance image and range image are fully registered because they both originate with the same echoed laser pulse. Next to extract 3D feature points using reflectance image and align the 3D feature points in two range scans into a coordinate system by the initial estimate. And then, we execute the method of Zhang et al. for the feature points of the two range scans. In this time, we can obtain an improving transformation matrix.

We align all points of the two range scans into a coordinate system using the improving transformation matrix, and we execute the method of Zhang et al. for all points of the two range scans. Finally, the two range scans are accurately aligned into a common coordinate system.

4. Geometry modeling

Each range scan contains a huge amount of points, if ten or hundred of range scans are aligned together, a very huge 3D data set will be produced. 3D modeling from the data set needs a better computer hardware environment. We must filter 3D data before modeling.

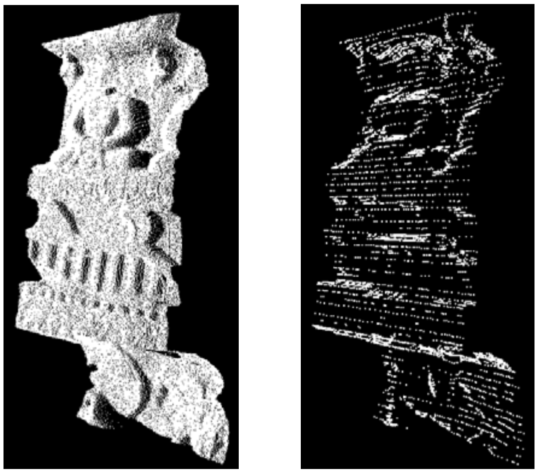
4.1 Filtering

The structure features are the main elements describing the shapes of culture heritage sites, we must try our best to retain the structure features when compress 3D data. We propose a filtering 3D data compression.

The laser points are organized on the 2D grid and a 2D point on the grid is corresponding a 3D point. We divide the grid into four rectangles with the same size. The two conditions are tested for each rectangle: (1) Whether the 3D points covered by the rectangle are on the same plane. (2) Whether the vertices of the rectangle are four effective points, or whether the vertices of the rectangle have three effective points. Effective point means that it is an actual point of the measured objects.

If both conditions are met, we retain these vertices of the rectangle corresponding the effective points, otherwise the rectangle is subdivided into four rectangles and the same tests are performed for each of them. The algorithm proceeds iteratively until the two conditions are fulfilled.

The filtering method retains structure features while reducing 3D points. Figure 2(a) is original data before filtering, and figure 2(b) is the result after filtering. The amount of points is reduced 88%.



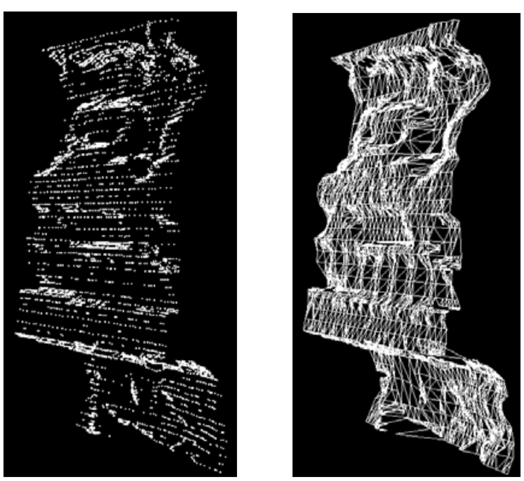
(a) (b)

Figure 2 3D Data Compression

(a) Original Data (148400 points); (b) The Result After Filtering (17919 points)

4.2 Modeling

V.Sequeira [12] and G.Turk [13] first built the mesh from a range scan, and then they zippered the meshes of all range scans into a single mesh model. Their methods cannot smoothen the errors from the registration of multi range scans and the errors of samples.



(a) (b)

Figure 3 Mesh Model

(a) Data After Compression; (b) 3D mesh

A volumetric method for building complex models from range images proposed by Curless and Levoy [14] can select the best mesh patch to fit 3D points. Due to the method is executed for all 3D points that are obtained through registration, it can remove some registration errors. Furthermore, the method can recognize holes and distinguish different objects.

After 3D data filtering, we perform the Curless and Levoy's method to obtain 3D models of culture heritage sites. Figure 3 is a mesh model from the filtered data using the Curless and Levoy's method.

5. Texture mapping

Cultural heritage sites contain not only rich geometric details but also color textures. When reconstructing realistic 3D digital models, all of information on the cultural heritage objects should be considered.

Cyrax2500 laser scanner that we use can only output range and laser reflectance data. To obtain color texture data of cultural heritage objects, we use a high- resolution digital camera. Thus, the problem of texture mapping appears, which is also a key technique of photometric modeling.

Generally speaking, a reflectance image is also an image and can be matched to any other image. We decided to employ the reflectance image as a vehicle for the alignment of range images with texture images.

Reflectance images are similar to texture images. Edges in reflectance images are generated due to several reasons: (1) Different colors or materials, (2) Range jumps, (3) Occluding boundaries. These edges can also be observed in texture images. So by aligning the discontinuities in reflectance images with those in texture images, we can determine the relative relationship between the range and texture views. We select Sobel to extract edge points: 3D reflectance edge points and 2D texture edge points. Our texture mapping steps are similar to the method of P. Debevec, et al [15]:

1. Extract edge points including 3D reflectance edge points and 2D texture edge points.
2. Project 3D edge points on 2D texture image and search corresponding points between two type edges.
3. Compute the camera model using Tsai's method [16].
4. Return 2, using the camera model, renew to project 3D edge points on 2D texture image and update corresponding points.

We perform the above process continuously until the mean error of correspondence less than a given value. Finally, we obtain an optimal camera model, and the texture images are mapped onto the 3D geometric model correctly.

6. Applications and results

We selected two projects as case studies and test beds for the new methods. In the first examples we generate a high-resolution, reality-based 3D model of Yungang grotto. In the second example we reconstruct real 3D digital models for some historic objects. Both projects demonstrate the benefits of digital preservation of cultural heritage.

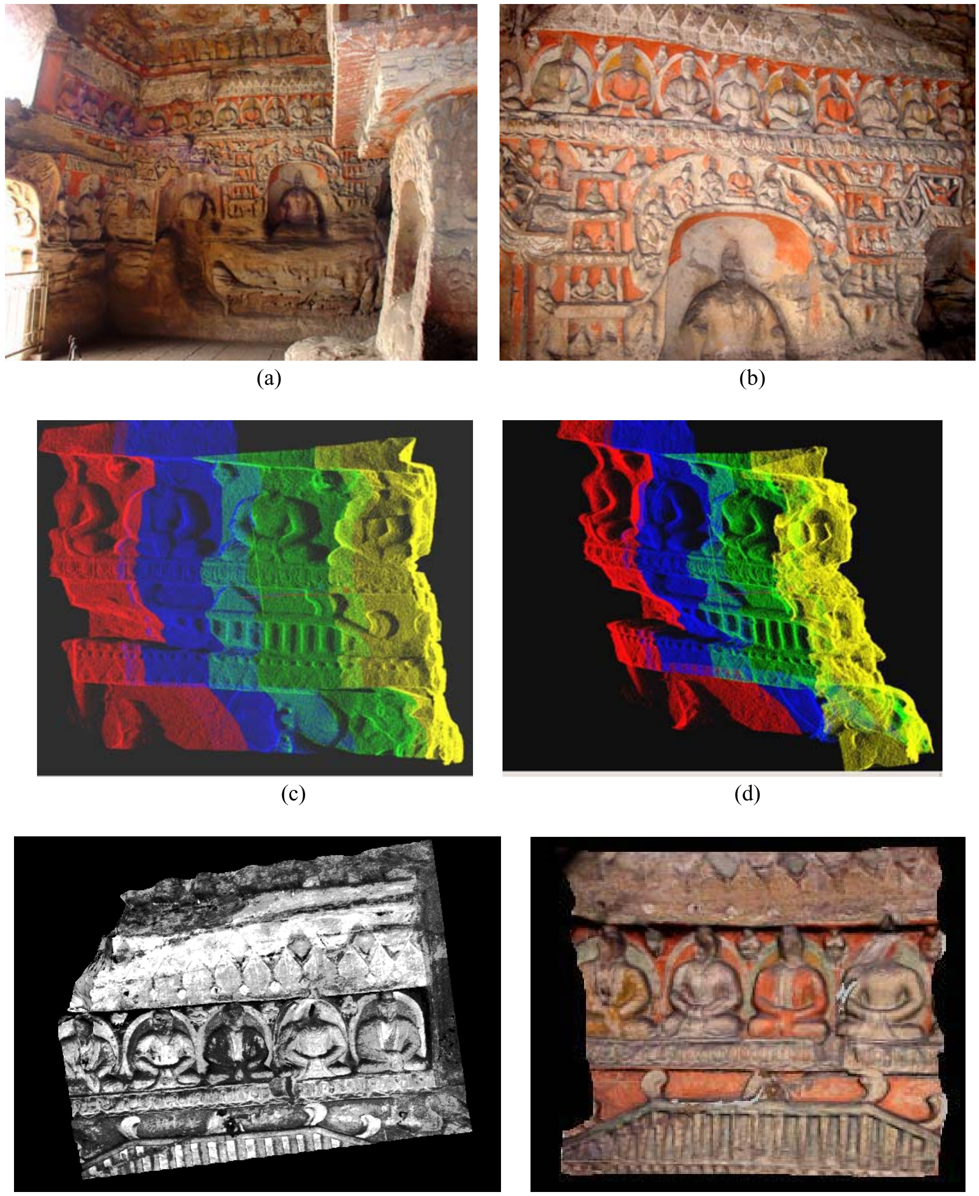


Figure 4 The Part Results of Yungang Grotto

(a) And (b) Are The Photos; (c) And (d) Are The Results of Registration; (e) 3D Geometric Model with Reflectance; (f) Real textured 3D Model.

6.1. Yungang grotto visualization

Yungang grotto was built 1500 years ago. With the environment changes, the grotto has been destroyed. We collected geometric data and texture data of the first cave of Yungang grotto using Cyrax2500 laser scanner and a high-resolution digital camera in 2003.

Firstly, we aligned all range scans into a common coordinate system. Secondly, we created geometric 3D models of Yungang grotto. Finally, we mapped the texture images onto the 3D geometric models. Figure 4 shows the part results we finished.

Figure 4(a) and (b) are the photos; figure 4(c) and (d) are the results of registration of three range scans; figure 4(e) is 3D geometric model with reflectance; figure 4(f) is real textured 3D model.

The digital preservation of Yungang grotto is a long-term task, and we only did a little work.

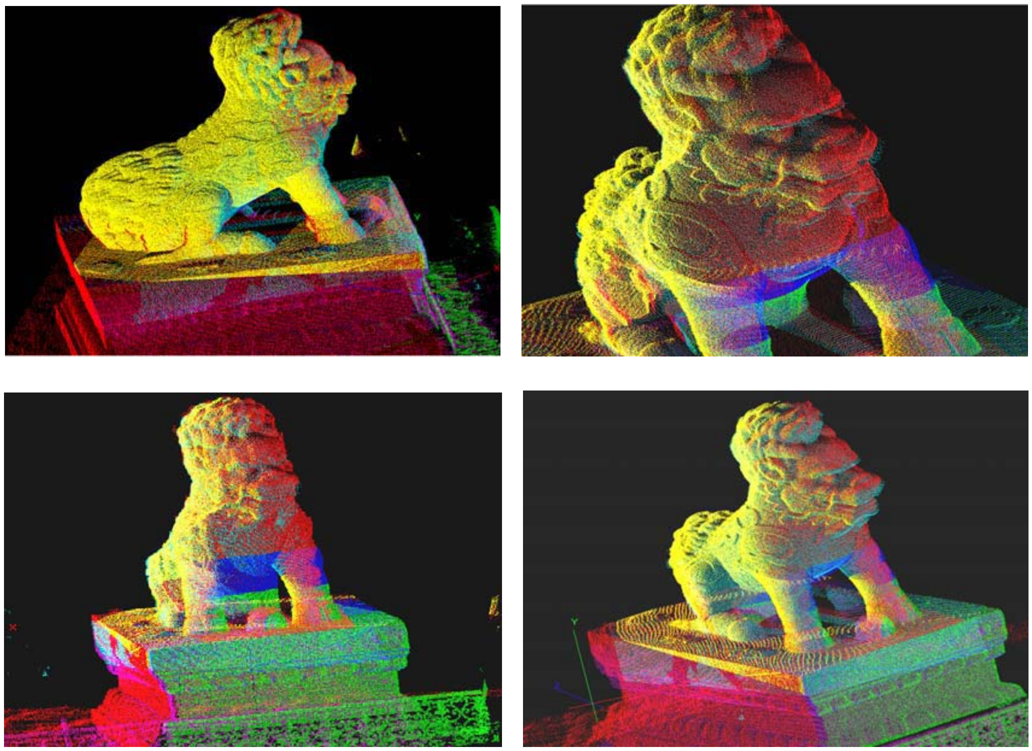


Figure 5 The Results of Registration

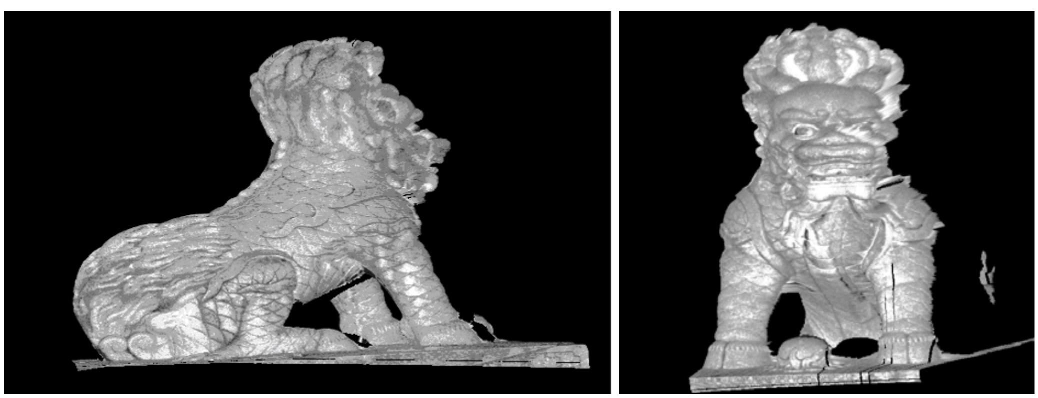


Figure 6 3D Geometric Model with Reflectance

6.2 Modeling of culture heritage objects

We also selected some cultural heritage objects to test the new methods proposed by us. The example is creating 3D model of Qinlin. Qinlin has a very irregular complex geometry.

Figure 5 is the registration result of eleven range scans of Qinlin. It shows our registration method is robustness.

Figure 6 is the 3D model of Qinlin, the model contains the geometric details. Figure 6 shows the results from two viewpoints.

Conclusions

Cultural heritage digitalization is complex system engineering, and it refers to the knowledge of many subjects. We only research some key problems. Our main contributes are written as follow:

- Proposed an algorithm of automatic registration of laser range data sets.
- Presented a multi-resolution compression method of 3D data.
- Address an iterative approach to camera calibration, realize texture mapping.

References

[1] Y.Pan, D.Lu. Digital Protection and Restoration of Dunhuang Mural (in Chinese). *Journal of system simulation*. 15(3): 310-314, 2003.

[2] X.Ma, W.Dui, et al. Walkthrough in Image-Based Virtual Indoor Environment (in Chinese). *Journal of Image and Graphics*. 6(1): 86-90,2001.

[3] M. Levoy, K. Pulli, et al. The digital Michelangelo project. *In Proceeding Siggraph' 2000*. 131–144, 2000.

[4] F. Bernardini, H. Rushmeier, et al. Building a digital model of Michelangelo's Florentine Piet`a. *IEEE Comp. Graph. and Applic.* 22(1):59–67, 2002.

[5] K. Ikeuchi, A. Nakazawa, et al. Creating virtual buddha statues through observation. *In IEEE Workshop on Applics. of Comp. Vision in Architecture*, 2003.

[6] J.A. Berladin, M. Picard, et al. Virtualizing a Byzantine crypt by combining high-resolution textures with laser scanner 3D data. *In Proceeding VMMS 2002*. 3–14, September 2002.

[7] P.J.Besl, N.D.Mckay. A method for registration of 3-D shapes. *IEEE Trans.* PAMI-14 (2):239-256,1992.

[8] K.Nishini and K.Ikeuchi. Robust simultaneous registration of multiple range images. *In Proceeding 5th Asian Conf. Computer Vision*. 454-461, 2002.

[9] I.Stamos and M.Leordeanu. Automated Feature-Based Range Registration of Urban Scenes of Large Scale. *IEEE International Conference of Computer Vision and Pattern Recognition*. 555-561, Vol. II, June 16–22, 2003.

[10] A. Johnson. Spin-Images: A Representation for 3-D Surface Matching. *PhD thesis*, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, Aug 1997.

[11] A. Zhang Aiwu, W. Sun Weidong et al. Fast Global Registration of Multiple 3D Data Sets from Outdoor Large Scenes (in Chinese). *High Technology Letters*.14(6): 6-10,2004.

[12] V. Sequeira，K.Ng, et al. Automated reconstruction of 3D models from real environments. *ISPRS Journal of Photogrammetry & Remote Sensing*. 54(1): 1–22, 1999.

[13] G. Turk and M. Levoy. Zippered polygon meshes from range images. *In SIGGRAPH 94*. 311–318, Jul 1994

[14] B.Curless and M.Levoy. A volumetric method for building complex models from range images. *In SIGGRAPH'96*. 303–312, 1996.

[15] P.E.Debevec, Y.Yu and G.D. Borshukov. View-Dependent Image-Based Rendering with Projective Texture Mapping. *Eurographics Rendering Workshop 1998*. 105-116.

[16] R. Lenz and R. Tsai. Techniques for calibration of the scale factor and image center for high accuracy 3-d machine vision metrology. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, PAMI-10(5): 713--720, Sept. 1988.

[17] C. Frueh and A. Zakhor. Data processing algorithms for generating textured 3D building facade meshes from laser scans and camera images. *In proceeding 3D Data Processing*. Visualization, and Transmission, Padua, Italy, June 2002.

1550-6037/05 $20.00 © 2005 IEEE