

Modeling and Visualization of Rock Carving

Cultural Heritage Sites in Dazu

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Abstract

Over the past few years, due to the advances in laser scanning techniques, 3D modeling software, computer power and virtual reality, many cultural heritage applications require 3D modeling and realistic visualization of the heritage models for various purposes. In such a project to virtualize the Dazu Rock Carvings, we proposed a commercially available solution. In this paper, we present this solution, along with the challenges we faced, the lessons we learned. We in particular focus on the pipeline designed to process data obtained from laser scanning and texture imaging, as well as the solutions developed to tackle problems encountered in web-based and offline applications of 3D models. Examples of our works are given and a video animation has been created to show the results.

1 Introduction

With over four thousand years of civilization, China has a great treasure of magnificent cultural heritage, including the intangibles and tangibles. Among those tangible cultural heritage sites exposed outdoor, which have long been under the threat of natural disasters or deterioration, how to prevent them from loss and dilapidation is becoming an urgent issue.

One way out seems to be the digital preservation by documenting the digital data of the heritage sites. On one hand, with the aid of 3D scanners, geometric information of the objects can be accurately acquired; on the other hand, a number of commercially available software tools are able to facilitate the process to achieve high quality visual effects and photorealism. Besides from their permanent persistence as archived data, the digitally reconstructed heritage models can be widely used in a range of applications, such as virtual restoration, archeology study, and particularly, exhibits in virtual museums for the world to unveil and appreciate their beauty.

In this project funded by the State Administration of Cultural Heritage, China, we examined the feasibility of recovering several famous cultural heritage sites by combining range data from 3D scanners and texture information captured by digital cameras. Among these sites, we select the Dazu Rock Carvings as an example to demonstrate the proposed pipeline.

The Dazu Rock Carvings, one of the largest five grottoes in China, are the representative works of the late period of China's grotto art. Consisting of more than

50,000 figures, 100,000 inscriptions, and known for their beauty and elegance, these carvings enjoy the title of the treasure masterpieces of the grotto art and cultural model. In 1999, the UNESCO World Heritage Committee, at its 23rd session, decided to inscribe the Dazu Rock Carvings of China, as the cultural property on the World Heritage List.

Beautiful and elegant as they are, the Dazu Rock Carvings indeed imposed us with enormous difficulties and challenges to digitize them, especially in terms of scale and geometric complexity. This paper will review these issues and address our processing pipeline. We begin with a survey of some large 3D projects pertaining to object and site modeling in the next section, as well as the techniques and methodologies they employed. Section 3 stresses the challenges in reconstructing the Dazu Rock Carvings and an overview of the solutions we proposed. Section 4 presents the details of our approach, followed by the examples of our works in section 5. Finally, concluding remarks are given in section 6.

2 Survey of some 3D projects

In the recent few years, a wide range of applications have employed three-dimensional scanning technology for the digital reconstruction of cultural heritage sites and works of art as scanning devices become less expensive and easier to use. Here in this section, some of such 3D projects will be surveyed.

Members of the National Research Council of Canada, developers of high-accuracy scanning equipment, have applied their technology to scanning paintings, sculptures, and archaeological sites. Recent work emphasizes the importance of portable, reliable equipment that can be easily deployed at the scanning site [2]. Jiang Yu Zheng et al. have scanned archaeological relics in cooperation with the Museum of Terra Cotta Warriors and Horses, China [14]. Among their goals were creating a database of information about the excavation site, testing and employing virtual restoration techniques. Marc Levoy and a team from Stanford University have undertaken a project to scan many of the sculptures of Michelangelo [16], including the 5m tall David in the Museo dell'Accademia. They have used several types of scanners, including a high-resolution laser triangulation system mounted on a custom-made mechanical gantry, and a time-of-flight long-range sensor. The large quantity of data collected is expected to have a major impact in future development of shape reconstruction algorithms.

Numerous other projects, such as the Great Buddha

project described by Miyazaki, D. et al. [15], and the work on the Coliseum in Rome presented by Gaiani et al. [13], have been conducted or are currently underway. Each project tries to optimize some part or all of the modeling phases using custom and commercial tools. In particular, Bernardini et al. [4, 5] published a good survey of these other projects along with their Michelangelo's Pietà project; they also proposed a commercially available solution for heritage recording through the application of virtualizing a Byzantine Crypt in [3].

Our method, although conceptually similar to that adopted in the Byzantine Crypt, replaces the geometry-texture registration with a different mapping pipeline to achieve better results in the Dazu Rock Carvings where the geometric topology is far more complicated. In addition, we also provide solutions to the problems encountered in both web-based and offline applications of 3D models. Satisfactory results have been obtained so far even though still far from perfect.

3 Dazu Rock Carvings: challenges and solutions

Issues related to laser scanning, especially for rock carving recording, are described in this section. Challenges associated with texturing are also addressed, along with the solutions to tackle these problems.

3.1 Issues related to texture acquisition

From the past experiences gained from many other laser-scanning projects, such as [11], quality of the intensity or color provided by some scanners via a single color channel is usually not so desirable. Most of the texture detail, which is of great interest to us, is missing simply because the scanners can only capture the intensity of the solitary scanned points. Furthermore, for applications where the models need significant simplification before they can be used, this situation is likely to be exacerbated as a consequence of the elimination of considerable color information. An alternative is to attach a high-resolution digital camera to the scanner and take a registered image with each scan. Notwithstanding, this will limit the flexibility to take the image at the best lighting conditions and have full control on the parameters that affect the sharpness and color quality. Therefore, it is more reasonable to acquire geometry and texture by two independent processes, and it is also more appealing to move around with the images taken from best possible positions.

3.2 Issues related to texture and geometry registration

In the literature of texture and geometry registration, various methods [6, 12, 17, 18, 19, 20] have been proposed to solve the problem of direct mapping of photographs onto a 3D model and reflectance modeling, either fully automatic or semi-automatic. At the meantime, as commercial software tools are becoming more and more capable in easing and automating this process, a few attempts have been made to introduce commercially available solutions to this problem. For instance, El-Hakim et al. [3] try to texture the virtualized Byzantine Crypt via some photogrammetric software. Effective as it

seems to be in cases like the Byzantine Crypt that are generally comprised of smooth walls, whose geometric form and topology is relatively regular, this approach is not necessarily feasible in cases with tremendous geometric complexity, such as the Dazu Rock Carvings, which are rich in folds and creases. Especially when it comes to occlusion, the difficulty of precise registration seems to increase exponentially. Moreover, since the high-resolution 2D images are taken separately under various lighting conditions, how to seamlessly blend them into a complete texture map without remarkable color jump remains as another issue to be considered.

3.3 Our approach

The approach we employed to model the Dazu Rock Carvings is an interactive procedure. Although it is tempting to create a model in a fully automatic way, given how much time and energy it could save, experience shows some involvement by the user can make a huge difference in the final quality or realism of the digital model. As far as our project is concerned, we rely on the ability of the user to take the 2D snapshots and pick the best way to texture-map the model. We also depend on the user's sensitivity to hue and luminance in texture blending. However, in order to achieve high quality digital products, the user will be well instructed and guided before they get down to work.

As to the issues discussed previously, we briefly summarize the features of our solution as follows:

- Allow imaging for texture to be carried out separately from the scanning.
- Allow for a two-step texture mapping strategy from texture space to scene space by introducing a 3D medium mapping surface enclosing the scene.
- Allows for manual adjustment of the color and brightness of the 2D images to synthesize a seamless and complete texture map for each model segment.

And details of this approach will be specified in the following section.

4 Details of the approach

Figure 1 shows an overview of our steps to create the textured 3D model. All of the steps can be performed with commercially available software tools.

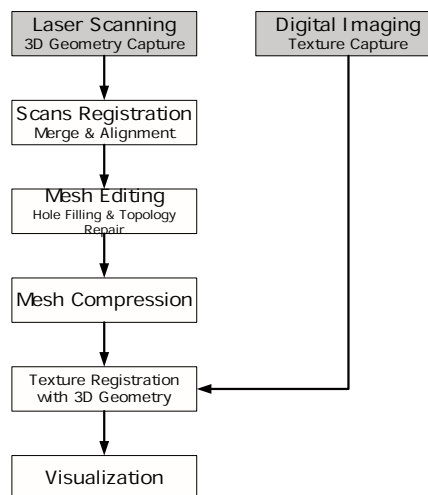


Figure 1. The 3D reconstruction pipeline

4.1 Data acquisition

We selected the Minolta® VIVID 910 as laser scanner, given the scanning precision (up to 0.0008 mm in the fine mode) and flexibility (three interchangeable lenses for variable scanning volumes between 100x80x40mm and 1200x900x400mm) it offers. In order to sample the top of some carvings, for instance, the Avalokitesvara of the Sun and Moon which is 12 feet tall from its pedestal, we had to add a large size tripod and a ladder to our hardware component. The scans obtained ought to share some overlapping boundary with their adjacent scans, and cover as many occluded regions as possible. Once this is nicely done, the difficulty and burden in scan-merging and hole-filling process will be considerably reduced.

The texture acquisition was separated from the laser scanning, performed usually during the best lighting conditions in a day. Besides, artificial lighting was essential in order to achieve good uniformity of illumination. In addition, experiences gained from the post processing tell us the image coordinate axis should basically parallel to the horizontal or vertical axis of the scene, through which the texture yields minimal distortion while mapped to the mesh. The digital camera used was the Canon® EOS 300D, which was also lens-interchangeable. The CCD sensor has a resolution of 3008×1960 pixels.

4.2 Geometry modeling

Our pipeline of geometric modeling with the input of a number of range images primarily consists of scans registration, merging, mesh editing and compression. The output of this procedure is a watertight irregular triangle mesh.

Usually a single scan is not sufficient to cover an object, since each observation provides only partial information. The range data obtained by observing an object or site from various perspectives and positions must then be registered - a procedure also known as scan alignment - in one coordinate system, mostly based on the iterative closest point (ICP) algorithm [7, 8]. ICP algorithms operate by finding matching points on two meshes, computing the rigid transformation that minimizes the sum of squared distances between these point pairs, and iterating until some convergence criterion is met. To initialize the algorithms, the two scans must be aligned approximately to the right positions.

Once the multiple range images have been registered, there is often a certain amount of overlap between different scans, which can be merged together to create a complete geometric model, a procedure called "merging" to extract one surface from multiple overlapped surfaces [9].

After merging, the non-redundant model can be triangulated into a triangular mesh, but it is still far from a perfect watertight mesh due to the existing holes introduced by occlusion or scan omission and topology faults generated in triangulation. These holes need to be repaired by applying various hole-filling techniques, such as adding new triangles, surface fitting etc., while the topology faults can be fixed by editing the neighboring edges and points interactively.

In most cases, meshes constructed so far are usually densely populated with triangles and huge in size, and still

require adequate compression before they can be actually used in various applications [1]. For example, in online presence and virtual visit where the speed of response of user interface is demanding, 3D models need to be reduced to a manageable size for manual interaction.

In our project, all of the above procedures are conducted with the techniques implemented in the commercially available software Polyworks® from Innovmetric®.

4.3 Texture mapping

As is mentioned in section 3.2, techniques that map real-scene images onto the geometric model, also known as IPT (Image Perspective Techniques) have gained a lot of interest. High-resolution color images can be precisely mapped onto the geometric model via photogrammetric approach. However, to accurately compute lens distortion, estimate 2D camera to 3D model pose and deal with hidden surfaces and incomplete views is usually challenging on the practical side [6], especially in cases like our project with a large amount of data to process and enormous complex geometric details to deal with. In our commercial solution to this problem, we have designed a pipeline to facilitate the registration of texture and geometry with the help of some well-known software packages.

A method developed by Bier and Sloan [10], allows for a two-step mapping from texture space to scene space by introducing a 3D medium mapping surface enclosing the scene. Independent of the scene surface, the basic idea of this method is a combination of two simple mappings: a mapping from 2D texture space to the surface of a simple medium surface, and a mapping from the medium surface to the surface of the objective scene. This technique has been implemented in the commercially available software 3D Studio Max® and is known as "UVW Mapping".

During the first step, the user visually segments the entire triangular mesh into a set of mutually exclusive patches, each of which is easy to find a basic way for mapping (e.g. planar, cubic, cylindrical and spherical). Then select a most suitable mapping for each segmented patch from the basic mappings. For instance, pick a spherical mapping for the head of the Buddha and a planar mapping for a wall painted with fresco. And then an initial texture map is generated by projecting the enclosed model segment onto the medium mapping surface.

In step two, the initial texture map is transferred to PhotoShop® (Adobe Inc.) for image stitching and blending. With the numerous features provided by PhotoShop®, texture segments extracted from photographs taken in different view points can be easily stitched and seamlessly blended together like mosaics. This interactive process requires the user precisely align the texture segments to the corresponding positions in the initial texture map, and adjust the color intensity of the segments, making them consistent in brightness. Afterwards, transfer the new texture map assembled in PhotoShop® back to 3D Studio Max®, remapping it onto the corresponding patch. Once all texture maps associated with the separated patches have been mapped onto the model, the user sometimes need to do a little adjustment to eliminate the color jump on the boundary of two neighboring patches. This can be easily handled in 3D Studio Max®.

The texture mapping pipeline is illustrated in figure 2.

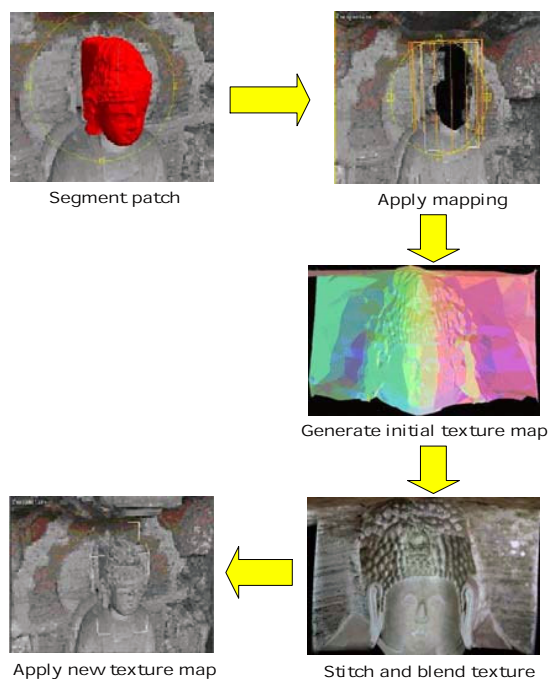


Figure 2. The texture mapping pipeline

4.4 Visualization

The digital representation of the shape and appearance of the Dazu Rock Carvings thus generated can be displayed, manipulated, archived and shared in many ways. In our project, aside from being documented as a fashion of digital preservation, the 3D models are also put on the spotlight in a virtual museum for online viewing, as well as displayed by a three-dimensional displayer for immersive offline visiting and study.

The major challenge faced with Web-based applications of the 3D models is the size of the files. Since the model files are in VRML'97, an ISO standard, the lack of binary (compressed) format makes the size of the files very large to download (E.g. many of them are 8 to 10 megabytes), very undesirable in internet transmission where speed of response is a priority while complete details and high accuracy are secondary. Compromising to this factor, we had to use models of lower resolution, and meanwhile compressed it to binary code with the Java Archive (JAR) technology. After compression, the file size is approximately one third of the uncompressed one on average. In addition, we have also developed a VRML browser on the client side; a viewer can freely navigate through the heritage sites with the cool features provided.

In the offline application where network transmission issue is no longer considered, high-resolution models are used. Here, the huge amount of data, for example the Avalokitesvara of the Sun and Moon is comprised of over 1,000,000 triangles and 150 MB in size including both geometry and texture, remains as the most challenging issue in model fast rendering. Given the fact that the models of the Dazu Rock Carvings are static, we tried to make good use of the vertex buffer object (VBO) in OpenGL rendering, which maximally takes advantage of the accelerating facility of the modern mainstream graphic chipset. In practice, as to the 150MB-in-size model, we have achieved a rendering speed of 42 frames per second

on a PC with 512M memory, 2.8GHz Pentium® IV CPU and a Radeon® 9800 Pro graphic card. Besides, with the help of 3D displayer, features that are small or only visible from a distance can be interactively and vividly examined, thus allowing the study of fine details such as tool marks or surface texture. Another product of this project is a movie that incorporates entertaining elements such as music and animation, taking the viewer to explore the evolution of the grottos.

5 Examples of our works

Among the hundreds of spots of rock carvings in Dazu, Chongqing, we have chosen only a handful of the most representative ones to digitize so far, given the time and energy we could afford. Meanwhile, as another important exhibit resource of our online cultural heritage museum, we have also digitally given eternal life to a few unearthed relics from the Museum of the Terra Cotta Warriors and Horses, Lin Tong, Xi'an, to which the same reconstructing pipeline was applied. The following figures are snapshots of the examples of our works.

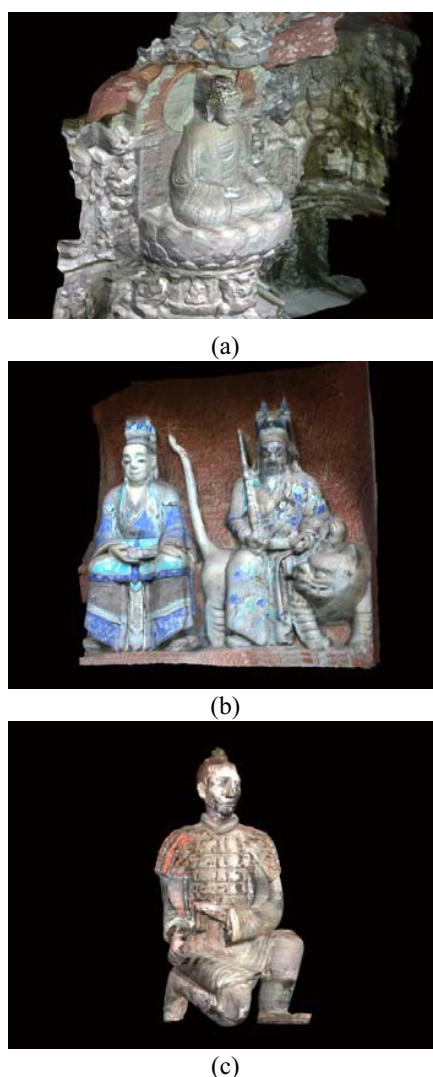


Figure 3. Examples of our works, a) Niche of Maitreya, future Buddha sutra, b) Liu Benzun, two heavenly kings, c) Blackface Terra-Cotta archer.

6 Concluding remarks

This paper presents a pipeline to digitally model and visualize the renowned cultural heritage sites of the Dazu Rock Carvings by combining laser scanner 3D data and high-resolution textures. From data acquisition to model visualization, from Dazu where the laser scans and images were gathered to Beijing where the processing was conducted, the entire project lasted for more than three months with a team of eight graduate students. Experiments performed with commercial software packages following the proposed procedure have yielded satisfactory results; realism from the 3D models can be experienced by either visiting the online exhibition or immersing oneself into the 3D stereo show in our offline demonstration.

The biggest problem remained is the excessive manual involvement in the modeling phases. On one hand, frequent interactions and low level automation makes it labor-intensive and time-consuming; on the other hand, the accuracy of the geometry-texture registration strongly relies on manual operations and interpretation, thus making the procedure error prone, even though many commercial software tools are so versatile that the problem can be alleviated to some degree. Besides, in our online show, the size of VRML files and the delay caused by unable to render the model before it is completely downloaded becomes another headache. These issues will not only motivate our exploration but also provide new objectives for our future work.

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