3D Modelling of Geological Fossils and Ores by Combining High-resolution Textures with 3D Scanning Data

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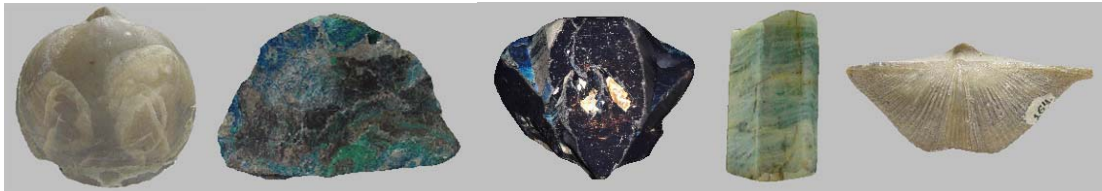*100871, Beijing, P.R.China*
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Figure 1.Texture-mapped models of fossils and ores.

Abstract. Remote 3D virtual reality systems for visualizing fossils and ores are a kind of efficient tools to facilitate communication and research in geology and palaeontology community. During the visualization procedure, we must keep not only the geometrical data but also the surface textures and color information. They are very important for the specialists to analyse the forming time and environments of the fossils and ores. In this paper, we describe a modelling procedure for generating 3D models of the fossils and ores based on 3D scanning data and color images. We analyse key problems that we encountered during the modelling procedure, and propose some new methods to solve them. The methods include scanning path planning, panoramic texture generation and texture mapping. Finally, some models for rare fossils and ores are presented.

1. Introduction

In the paper, we introduce some of our work on 3D modelling of fossils and ores as part of an effort to build a geological digital museum (Figure 1), whose top web page is shown in Figure 2. The key issue in the modelling procedure is the visual realism of the models, which requires accurate digital representations of both the geometrical shapes and surface attributes, including surface textures and colors. It is necessary to keep a high level of 3D geometrical details to provide the geologists or palaeontologists with critical evidence for their hypotheses on the forming times and environments of the artifacts. At the same time, the investigation into some geological or palaeontologic facts depends heavily on the textures and colors that tell stories only the specialists can understand. When combined with virtual reality (VR) and animation technology, the ancient environments may be reconstructed before us, which is impossible without 3D modelling technology.

In fact, there have been a number of projects related to digital heritage based on 3D modelling technologies. Beraldin et al. tried to generate a photo-realistic 3D model of the Crypt of Santa Christina [4]. Rocchini and his teammates proposed a new approach to producing a smooth joint between different images that map on adjacent sections of surfaces based on texture blending, which decreases the boundary effects [5,12,13] in the image stitching. However, the pictorial details will be blurred after this blending.

Figure 2. The top web page of the Geological Digital Museum, Peking University (http://museum.pku.edu.cn).

Levoy et al. spent a year digitising the shape and color of large statues in Italy [8]. They manufactured a laser triangulation scanner for handling very large target objects and developed a lot of new methods for the post-processing of the acquired data. The techniques they proposed are very effective for large objects, but when being faced with fine tiny objects, they will not work well at all times. Almost at the same time, an IBM team scanned Michelangelo's Pietà under field conditions [2]. The most outstanding point of their work is the "win-win" result for the historians and technologists. From the historical perspective, it gives them a new way to solve the 450-year-old mystery [1]; from the technological perspective, this modelling procedure and the acquired data offer plenty of new algorithms for current research goals.

The National Research Council of Canada (NRC) focused on building robust, field-deployable systems [6]. They did many different kinds of experiments, ranging from the generally interesting objects like the archaeological site, and sculptures, to the extraordinary objects like paintings and Tylosaurus sp. Mosasaur fossils [9], to test the systems. Ikeuchi et al. [7] describe the pipeline of a modelling procedure for a large Buddha. Their efforts concentrate on the robust simultaneous registration and integration, eigen-texture rendering, and restoration of original states [11].

In general, there are two different approaches for constructing photo-realistic 3D models. The first is to get geometry and color data simultaneously with only polychrome scanning laser slits or spots. In this case, the acquired data are multi-view range images with a color value assigned to each 3D vertex in the range data. Another way is to collect the geometry and color data with laser scanners and color cameras separately. Here, the acquired data are multi-view range and color images, which are recorded with different resolution and formats. In our method, we choose to use the latter since it provides support for mipmap texture mapping that is an important process in visualization with different levels of detail.

As compared with the previous applications, our task for modelling of fossils and ores has following problems:

1) The sizes of the objects are usually much smaller than the marble statues and historical sites which are typical objects in most modelling projects, while the modelling quality of details in both the geometry and textures may be required to a higher degree.

2) The range and color images have to be collected from multiple viewpoints, and the viewpoints for taking color image are usually different from those for 3D scanning. These multi-view data will make the registration process very difficult to implement efficiently.

3) Stitching and blending the multi-view texture mapping patches will lead to boundary effects, i.e. there are sharp changes of surface attributes at the stitching boundaries.

For maximizing the technical merits of using commercially available software and hardware to solve these problems, we exploit some new strategies. We decouple the acquisition of shape and surface attributes, which gives us great freedom to choose 3D scanners and color digital cameras to guarantee high-level modelling quality of details. At the same time, scanning path planning provides a technology suitable for improving the quality of the geometry, and panoramic texture generation is good for color image registration. During the texture mapping procedure, deliberate processing on the stitching boundaries will contribute to eliminating the boundary effects effectively.

2. Overview of the modelling system

In this section, the outline of the modelling procedure used in our research is described first. Then, the main equipments used in the procedure are introduced.

2.1. The general processing pipeline

The fossils and ores to be modelled in our method vary greatly in their volumes, colors and made-up materials. For example, the volumes of them range from about 25mm×17mm×15mm to 160mm×100mm×45mm, the colors change from maize to dark purple, and the materials are jade-like, metallic, or stone-like. The variety of the objects makes the data acquisition and other relevant processes difficult to accomplish. In the modelling pipeline, following points have to be paid attention to:

   1) Preserving geometry of the object accurately.

   2) Stitching the color images of all aspects of the target object to acquire a panoramic texture image with least high-lights and shadows.

   3) Integrating the geometry model and panoramic texture to generate a complete realistic digital model with least boundary effects.

   The processing pipeline is shown in Figure 3.

Range data acquisition   Color image acquisition

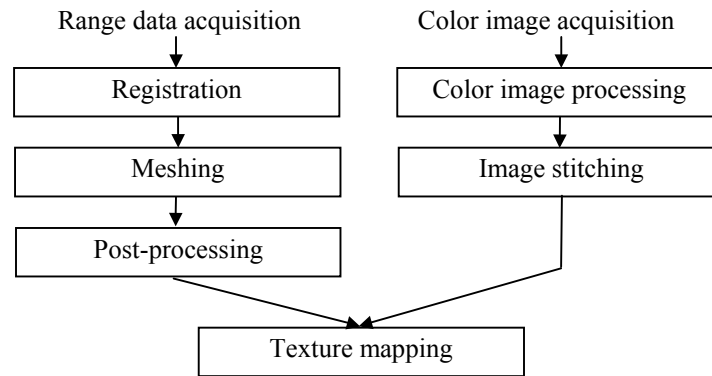| Registration	Color image processing
Meshing	Image stitching
Post-processing	

Texture mapping

Figure 3. Processing pipeline.

2.2. The equipments

To deal with the variety of the fossils and ores, we use two kinds of 3D laser scanners to get range images, *FastScan* and *VIVID700*. Their specifications are summarized in Table 1. A lens-interchangeable digital camera, *Sony DSC-F707*, is used for the texture acquisition. Its CCD sensor has a resolution of 2560×1920 pixels. The 3D graphics processing softwares *Polyworks* and *Maya 4.0* are the main software tools used to process mesh data and map textures.

   Since the scanning principle of 3D laser scanners we used is almost the same, we only describe the *FastScan* system here. In the *FastScan* laser scanner, the range-finding optics is contained in the handheld Wand, and the tracking is done with a Polhemus FASTRAK magnetic tracker. The *FastScan* electronics, including the tracker, are contained in a Processing Unit (PU). As shown in Figure 4(a), we sweep the target object with the *FastScan* "Magic Wand" to get its 3D information. The ellipses mark the range-finding optics components, where E1 and E3 are two miniature cameras that form a stereo vision system, and E2 is a laser aperture. The rectangles mark the magnetic tracker components, where R1 is the Magnetic Field Transmitter (MFT) and R2 the Magnetic Field Receiver (MFR). It is noticed that since the metallic materials may affect the accuracy of the magnetic localization system, we choose another laser scanner, *VIVID 700*, to acquire the range data for metallic ores. The arrows indicate the directions of the laser beams. During the scanning procedure, the distance between the MFT and target object must be kept less than 750mm to guarantee the scanning accuracy. While the laser is sweeping the object, two miniature cameras and the projected laser slice on the object form a triangle. Therefore, the distance between the scanning point and scanner can be calculated according to the triangle measuring principle. At the same time, the MFR gets the electromagnetic signal emitted by the MFT to confirm the center of MFT, and hence 3D positions of the scanner can

be tracked. Then the scanning data acquired at each laser slice are registered automatically by using the scanner's positions.
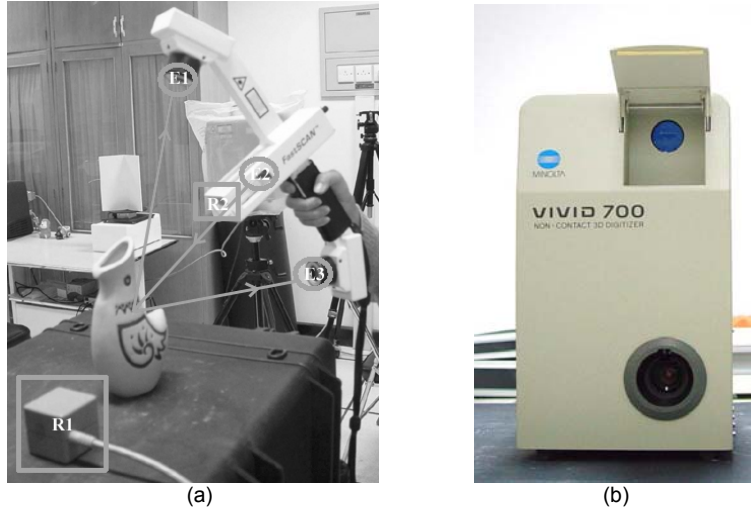

(a)   (b)

Figure 4.　(a) The scanning scene using FastScan; (b) VIVID700.

Table 1.　3D laser scanner specification

	SPECIFICATION	VALUE
FastScan	Distance to object (mm)	150~750
	Laser line length	150mm@200mm
	Scanning rate Resolution (line to line)	50 lines/second 1mm@50mm/second
	Resolution along the laser line	Depend on wand-object range, typically 0.5mm@200mm range
	Scanner weight and size	Portable and lightweight
VIVID 700	Distance to object (mm)	600~2500
	Scanning time	0.6 seconds
	Scanned area (x,y) (mm)	70×70 to 1100×1100
	Resolution (x,y,z)	$200 \times 200 \times 256$ points
	Scanner size (mm)	$210W \times 326D \times 367H$
	Scanner weight (kg)	9

3. Modelling Procedure

In this section, we describe three major processes in our modelling system: geometrical modelling, texture stitching and texture mapping.

3.1. Geometrical modelling procedure

During the scanning process, we should pay attention to the following problems: 1) *FastScan* is tracked by magnetic sensors, which are sensitive to metallic materials. Therefore, any metallic objects have to be kept away from the site of scanning. For scanning metallic ores, *VIVID 700* is used instead. 2) The intensity of the laser also affects the quality of data: if it is too weak, some data points are lost; if it is too strong, on the other hand, the noises of data increase sharply. 3) In order to make the post-processing easy and reduce surface topological errors, the scanning path has to be planned carefully. As shown in Figure 5(a), the data scanned without the scanning path planning contain many noises and the

surface geometrical details are blurred. The result with scanning path planning is shown in Figure 5(b), where the noises are reduced greatly and thus the surface geometrical details become much more evident.
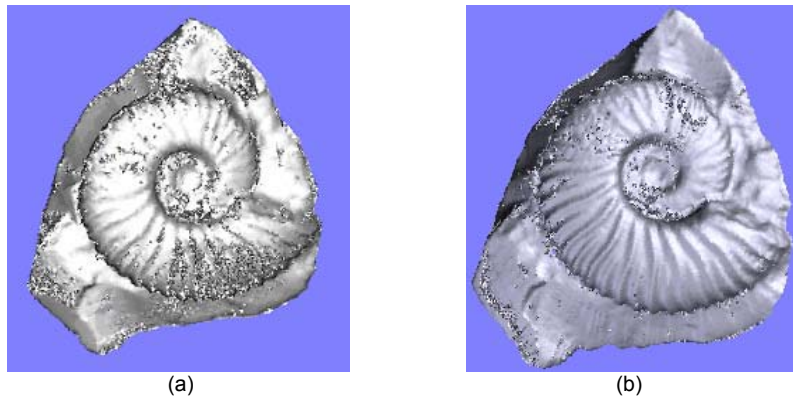

Figure 5. Effects of the scanning   (a) without path planning;   (b) with path planning.

Another problem we encountered in the data collection is the diffusion of scanning laser slices on the surfaces of jade-like semitransparent ores. To decrease the transparency, we coat them thinly with a kind of easy-removable white dye, and then scan them with the scanner.

The limitation on scanning range of the 3D scanner always keep us from acquiring data for the whole object surface if the object is fixed on one pose. Therefore, we have to move the object into different poses and then scan it repeatedly. On the one hand, the *FastScan* and the *VIVID 700* systems can only handle the integration of scans for an object with fixed pose. At the same time, many factors may affect the registration accuracy, such as vibration in the scanner movement and systematic errors caused by calibration. To enhance the registration accuracy, we use the *Polyworks* package to get fine alignments of the data patches. Figure 6 demonstrates the registration process in which several patches of scans form a part of the model in *Polyworks*.
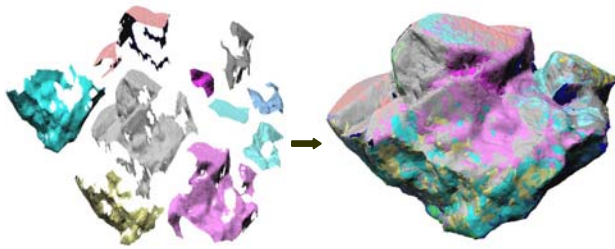

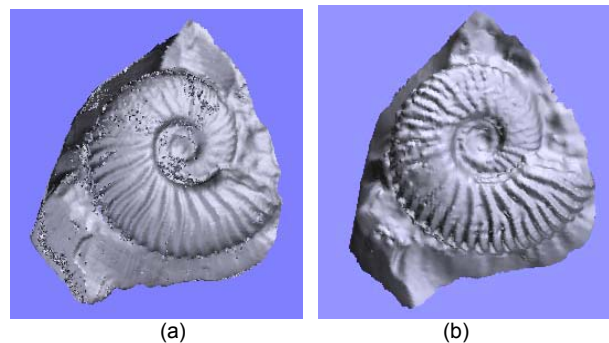Figure 6.   Registration procedure, from left to right.

Figure 7. Models (a) before post-processing; (b) after post-processing.

After the scanning and registration, the acquired 3D data are often represented as a point cloud or an irregular mesh with complex structures. The following texture mapping requires us to rebuild it to get a regular triangular mesh.

Holes, noises and topological errors are unavoidable in the raw data and they will damage the quality of the 3D geometrical model seriously. Hence we should also perform some post-processing to eliminate the topological errors, fill holes and filter out noises before texture mapping. Usually three points on the edges of a hole are chosen to form a new triangle to fill the hole. Most of the noises appear as abnormal protuberances or hollows, and local smoothing is the main method to erase them. All of the post-processing is done with *Polyworks*. The comparison of the model before and after the post-processing is shown in Figure 7.

3.2. Panoramic texture stitching

Our color image acquisition system is very simple. It is made up of a high-resolution digital camera and a number of white paper boards as reflectors for illumination. Because of the view field restriction of the camera, we need to get several images from different directions while keeping uniform illumination at each viewpoint. This requires careful controlling of the photographing conditions, especially for the lighting. However, in usual indoor environments, where the light source is composed of several point lights, it is difficult to make the lighting condition as optimal as we desire. The uneven lighting could cause shadows and high-lights in a single image as well as changing hues between different images.

One of our methods is to put a number of white boards near the object to make the indoor lighting gentler and uniform. In order to keep the hues of these images unchanged when taking images from different viewpoints, the camera and the white boards must be fixed. The only changes are orientations of the target object. Moreover, we can make further adjustment to the brightness and hues of each image with image processing software to alleviate the ill effects. After the processing, all of the images can be stitched to form a panoramic texture image.

However, using white boards alone is not enough to solve the lighting problem, especially when the object is metal or transparent. Some of semi-transparent or metallic objects are photographed outdoors in gloomy day with a heavy snow background. The images of a Pyrite (FeS2) ore taken in different lighting conditions are shown in Figure 8. The image in Figure 8(a) is taken indoors with a lot of shadows and high-lights. The image in Figure 8(b) is taken in a outdoor snow background and we can find hardly any shadows and high-lights.
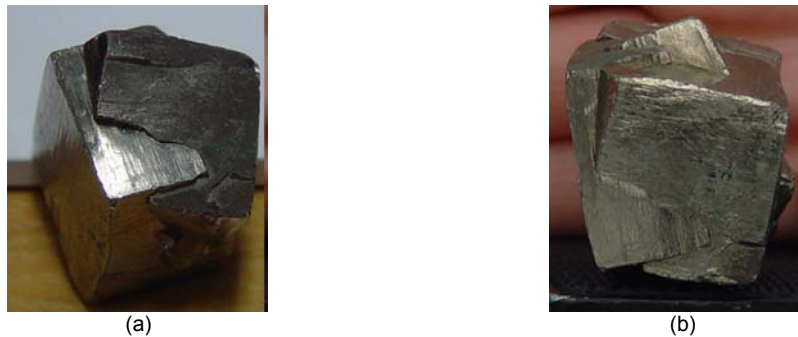

| (a) | (b) |

Figure 8.   (a) Image taken in a room with six point lights; (b) Image taken outside in a gloomy snow background.

3.3. Texture mapping

The focus of the texture mapping is to build a one-to-one correspondence relationship between 3D data points in the geometrical model and pixels in the texture image. The main processes are: 1) Project the 3D geometrical model on a plane at a certain orientation. 2) Align the outline of the object on the projecting plane with that in the corresponding texture image. 3) Give the color of a pixel to its corresponding vertex.   4) Change the projecting orientation and repeat above steps until all sides of the object are properly texture-mapped. Several projecting planes are required during the whole texture mapping process. They correspond to different texture mapping patches of the model. Unfortunately, on the boundaries of the patches, there always exist undesirable boundary effects.
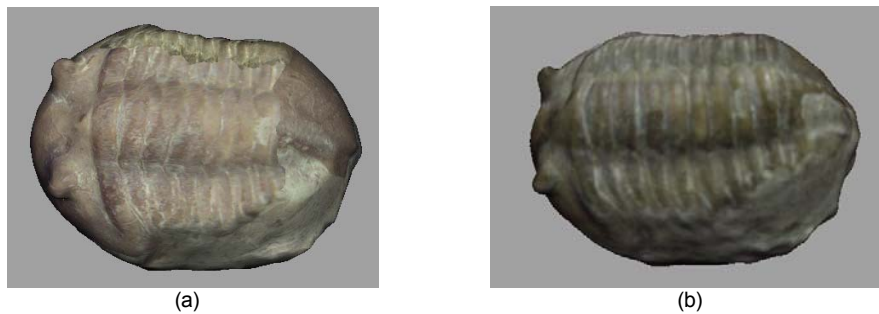

| (a) | (b) |

Figure 9. (a) Texture mapping without boundary choice; (b) with boundary choice.

One solution to the problem is to examine the distribution of the object's textures before the texture mapping to find natural boundaries of the textures, where the color or the pictorial details changes sharply. Extracting these natural boundaries and using them as the boundaries of different texture mapping patches can decrease the discontinuity in the surface attributes. The result without the boundary searching is shown in Figure 9(a), while the result with the searching is shown in Figure 9(b). In the latter, since the real texture and color boundaries are chosen as the texture patch boundaries, the texture transition is smoother.

4. Results

Figure 10 shows the models of a number of fossils and ores. Figure 10(a) illustrates the geometrical models of fossils and ores, (b), (c) and (d) are their texture-mapped models seen from different angles, (e) is the photographs of these objects. Some data for the models are listed in Table 2. The details of grains in the image given in the second row of (b) are important for paleontologists to analyse the forming time and environments of the Desheyesites Deshayesi fossil. The number 384 of the fossil can also be seen clearly at the left bottom of the model.

Table 2.　Data for the models

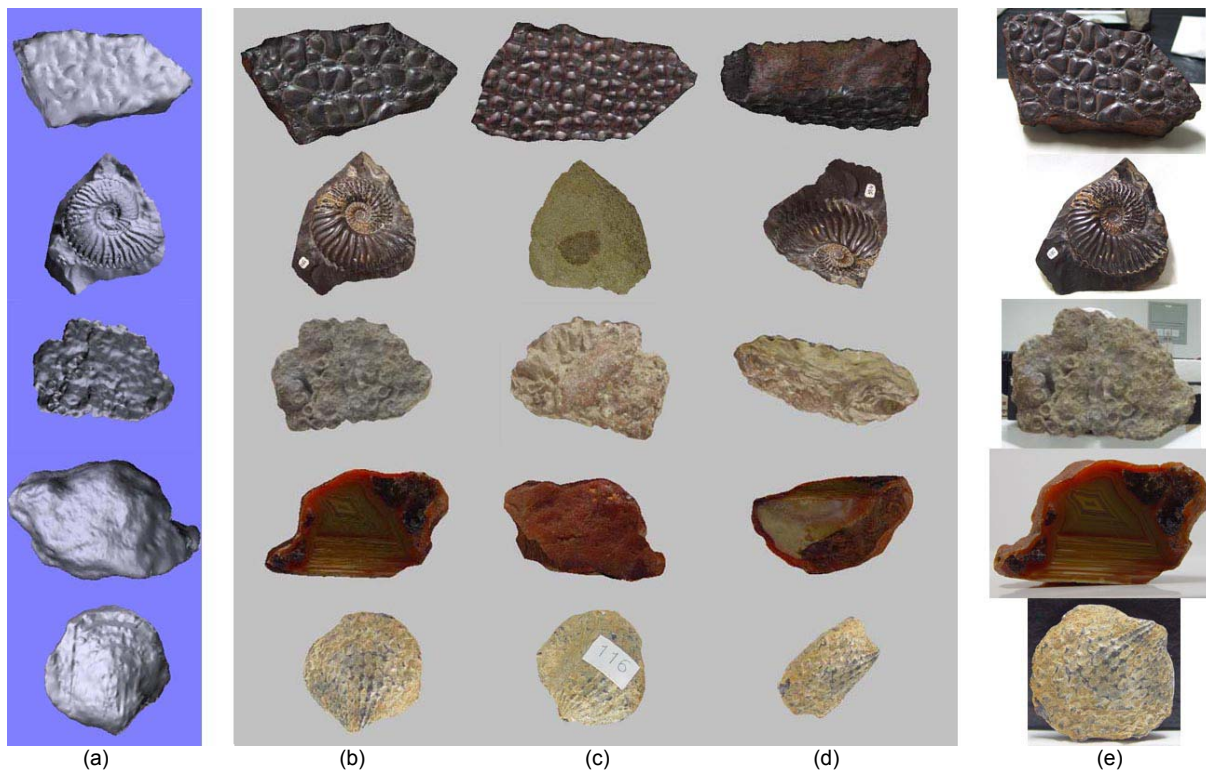|	length/width/thickness（mm）	vertices	triangles	color images
Hematite	160/100/45	5002	10000	7
Desheyesites Deshayesi	100/95/25	2509	5000	2
Coral fossil	95/68/25	27559	55114	4
Carnelian	60/35/31	25002	50000	6
Spinatrypa sp	25/25/10	10002	20000	2

(a)　　　　(b)　　　　(c)　　　　(d)　　　　(e)

Figure 10.　The model of Carnelian, Desheyesites Deshayesi fossil, Coral fossil, Hematite and Spinatrypa sp. fossil (from top to bottom).

5. Conclusions

Because of the strong requirements of paleontologists and geologists, the 3D digitalization of fossils and ores is of great importance in the related research fields. It requires not only keeping accurate geometrical details but also recovering precise textures. This paper introduced a modeling procedure for the digitization, and analyzed difficulties we encountered in this procedure. Some solutions that partly solve the problems were proposed. Finally the experimental results demonstrated the efficiency of our methods.

However, there still exist some problems on processing boundary effects. Though these effects are weakened, it is very difficult to erase them completely. This should be paid much attention in our future research.

References

[1]   J. Abouaf, The Florentine Pietà: Can Visualization Solve the 450-Year-Old Mystery?, *IEEE Computer Graphics and Application*, Vol. 19, No. 1, 1999, pp. 6-10.

[2]   F. Bernardini, H. Rushmeier, I. M. Martin, J. Mittleman, and G. Taubin, Building a Digital Model of Michelangelo's Florentine Pietà, *IEEE Computer Graphics and Application*, Vol. 22, No. 1, 2002, pp. 59-67.

[3]   F. Bernardini, L.M. Martin and H. Rushmeier, High-Quality Texture Reconstruction from Multiple Scans, *IEEE Trans. on Visualization and Computer Graphics*, Vol. 7, No. 4, 2001, pp. 318-332.

[4]   J.A. Beraldin, M. Picard, S.F. El-Hakim, G. Godin, V. Valzano, A. Bandiera and C. Latouche, "Virtualizing a Byzantine Crypt by Combining High-resolution Textures with Laser Scanner 3D Data". *Proc. 8th Int. Conf. on Virtual Systems and Multimedia*, 2002, pp. 3-14.

[5]   P. Cignoni, C. Montani, C. Rocchini, R. Scopigno and M. Tarini, Preserving Attribute Values on Simplified Meshes by Resampling Detail Textures, *The Visual Computer*, Vol. 15, No. 10, 1999, pp. 519-539.

[6]   G.Godin, J.-A. Beraldin, J. Taylor, L. Cournoyer, M. Rioux, S. El-Hakim, R. Baribeau, F. Blais, and P. Boulanger, Active Optical 3D Imaging for Heritage Applications, *IEEE Computer Graphics and Application*, Vol. 22, No. 5, 2002, pp. 24-36.

[7]   K. Ikeuchi, K. Nishino, and A. Nakazawa, Towards the Digital Archive of Cultural Heritages-Preservation and Restoration of Ancestral Assets through Observation, *Proc. 8th Int. Conf. on Virtual Systems and Multimedia*, 2002, pp. 920-925.

[8]   M. Levoy et al., The Digital Michelangelo Project, *Proc. Int. Conf. 3-D Digital Imaging and Modelling*, 1999, pp. 2-11.

[9]   P.D. Lyons, M. Rioux, and R.T. Patterson, Application of a Three-Dimensional Color Laser Scanner to Palaeontology: an Interactive Model of a Juvenile Tylosaurus SP. Basisphenoid-Basioccipital, *Palaeontologia Electronica*, Vol. 3, No. 2, art.4: 16pp.. http://palaeo-electronica.org/200 0_2/neural/ issue2_00.htm.

[10] P.J. Neugebauer and K. Klein, Texturing 3D Models of Real World Objects from Multiple Unregistered Photographic Views, *Computer Graphics Forum*, Vol. 18, No. 3, 1999, pp. 245-256.

[11] K. Nishino, K. Hara, R.T. Tan, D. Miyazaki, and K. Ikeuchi, Photometric Aspects on the Preservation of Cultural Assets, *Proc. 8th Int. Conf. on Virtual Systems and Multimedia*, 2002, pp. 926-933.

[12] C. Rocchini, P. Cignoni and C. Montani, Multiple Textures Stitching and Blending on 3D Objects, *Proc. 10th Eurographics workshop on Rendering*, 1999, pp. 127-138.

[13] C. Rocchini, P. Cignoni, C. Montani and R. Scopigno, Acquiring, Stitching and Blending Diffuse Appearance Attributes on 3D Models, *The Visual Computer*, Vol. 18, No. 3, 2002, pp. 186-204.