LASER ECHO INTENSITY BASED TEXTURE MAPPING OF 3D SCAN MESH

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ABSTRACT:

The rapid development of multiple sensors leads to a new era of data explosion. How to deal with the huge amount of the data is a hot topic in many fields. In the photogrammetry and computer vision community, the newly emerged laser scanning technology has been paid much attention by researchers doing 3D reconstruction applications. In order to protect the various invaluable cultural heritage, the laser scanning is adopted to get the surface geometric data of the heritage. Most laser scanners do not have the ability to acquire colour information. So texture mapping is the most common way to get a colourful model. We present a texture mapping system which can handle this problem efficiently based on the photogrammetric way and some computer graphics knowledge. A 3D rendering environment is constructed to visualize the texture mapping process. Many useful manual edit tools is also available in our system to handle the complex situation which can not be done automatically at present. The traditional concept of relative orientation and absolute orientation is adopted to rapidly align the images and the triangle mesh. Then, mesh patches generated by the smoothness constraint based region growing method are assigned to corresponding images. To achieve better visualization results, the local distortion adjustment and the colour blending algorithm are implemented in our system. Though many error factors are not take into account in this system for simplification, the system can work well on generating textured model with nice visualization. Combining automatic and semi-automatic way, the system can handle the texture mapping procedure in cultural heritage digitization efficiently.

1. INTRODUCTION

1.1 Introduction

In the work of generating textured digital surface model, laser scanners are often used to get the surface geometric information of objects. Although laser scanners can quickly obtain high-precision geometric information of objects, most of the laser scanners can not acquire the object's texture and colour information directly. In practice, the non-metric digital camera with high resolution is used to obtain surface texture. However, due to the lack of robust texture mapping algorithm with high accuracy and efficiency, the efficiency of generating textured 3D models of the real world is not as high as the speed of laser scanning. Speeding up this process without losing much precision becomes a hot topic in photogrammetry and computer vision community.

This paper is based on the project of "Digital Dunhuang ". The Dunhuang Mogao grottoes is a world famous cultural heritage. It’s regarded as a miracle remained after cultural collision between east and west. But there are fearful diseases for all the grottoes in different extents and the speed of painted statues damage and fresco degradation is wondrously horrendous. The government pay much attention to the cultural heritage protection. Despite the physics protection, digital technology can be used to document the cultural heritage, thus give a forever live to the Mogao grottoes in digital world.

To make the digital documentation of the cultural heritage of Dunhuang Mogao Grottoes, a laser scanner is used to obtain the geometric information of the cave, fresco, Buddha and etc. For there are many proposed methods and technologies and commercial software available for geometric processing, this paper focus on the texture mapping problem. Concretely, it means the 2D optical image wrapping on the triangle mesh. In the data acquiring period, while acquiring the geometric information, the scanner will record the intensity of each reflected laser ray. Because an 2d image can be generated from the reflected intensity information(Sequeira, Ng et al., 1999), the intensity information is used to generate textured models.

To achieve this efficient framework for mapping multiple images onto arbitrary 3D scan models with minimum user interaction, we make heavy use of existing algorithms and present a system for 3D scan model texture mapping, which can handle the texture mapping problem with high efficiency.

1.2 Related Work

Many work has been done in the geometric modelling aspect of cultural heritage documentation. A set of surface reconstruction algorithm and commercial package on 3D geometric editing are

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available. Thus, many researchers pay much attention in the texture mapping procedure.
(Heckbert, 1983)proposed the "perspective texture mapping " technology, in the paper, a camera parameters was used to transform the vertex of 3D polygon mesh to the pixel coordinate in the computer screen. This approach is quite useful when modelling the real world because it simulated the very moment of photography. (Heckbert, 1986)gave an extreme introduction of the texture mapping technology and make an formula list of many kinds of texture mapping methods. In computer graphics field, The irregular 3D surface mesh always be parameterized to a plane and 2d image can be wrapped to the parameterized mesh. In (Haker, Angenent et al., 2000), the author give an introduce to a conformal surface parameterization method relies on certain conformal mappings from differential geometry. The method can keep the angles conformal after mapping. This method can achieve the result that the appearance of the image after mapping. However, the method is not suitable for texture mapping for the real world scene.
The registration procedure in our paper is similar to the method mentioned in (Dias, Sequeira et al., 2002). In the paper, the intensity information is also combined to generate the 3D textured model of real world scenes. After rescaling the images. The Harris feature detector is adopted to match the two images from different sensors. This method is highly semi-automatic. The operator have to select a similar region from the intensity image for every image.
There are different solutions for the texture mapping problem in different fields. In computer graphics, the surface parameterization is the common way to mapping an 2D image onto an 3D surface.(Zhang, Mischaikow et al., 2005)propose a feature-based Surface Parameterization which can be used to map the images to the mesh. A image based error measurement was also present to evaluate the result of the parameterization.(Zhou, Wang et al., 2005)gave a automatic way to mapping any images onto an arbitrary surface. After the user specifying correspondence between images and surface, they take a partition of the surface and images by a shortest path searching between correspondences. Then a set of optimization process in texture coordinate and boundary is taken to refine the mapping result. This method is also not so suitable for the real world scene reconstruction. (Wang, Zhang et al., 2008)introduce a method to mapping the video sequence images onto the corresponding 3D model. The process first register one images to the 3D model. Then, the sequence images are registered to generate a mosaic texture. The least square local geometric error optimization is carried out to compute the texture coordinate of the vertices of the 3D model. This method is quite useful for dealing with some local deformation.
For the texture mapping of the real world scenario, the photogrammetry way combined with some ability to deal with local non-rigid deformation is more suitable. Though our method takes a rigid model to do the texture mapping, some tools for local distortion adjustment are supplied.

1.3 Paper Overview

This paper introduces the texture mapping workflow as follows: section 2 gives an overview of our texture mapping system describing the trunk of the system. Section 3 describes the whole registration procedure between the images and 3D scan mesh in detail, including intensity image generating, image feature extraction and matching and relative orientation. Section 4 shows the image processing procedure taking place on the 3D triangle mesh, including assigning images to a patch of mesh, local distortion adjustment and texture blending process. By this step, the visualization result can be largely improved.
Finally, from the system described above, a conclusion is drawn and the future work of texture mapping is given.

2. SYSTEM OVERVIEW

In this paper ,the texture mapping system takes three types of data as direct input, the original point cloud with echo intensity, the reconstructed triangle mesh from point cloud and the texture images. The system can be divided into three parts by function. The subsection below represent the three parts and the whole workflow is shown in the Fig1.

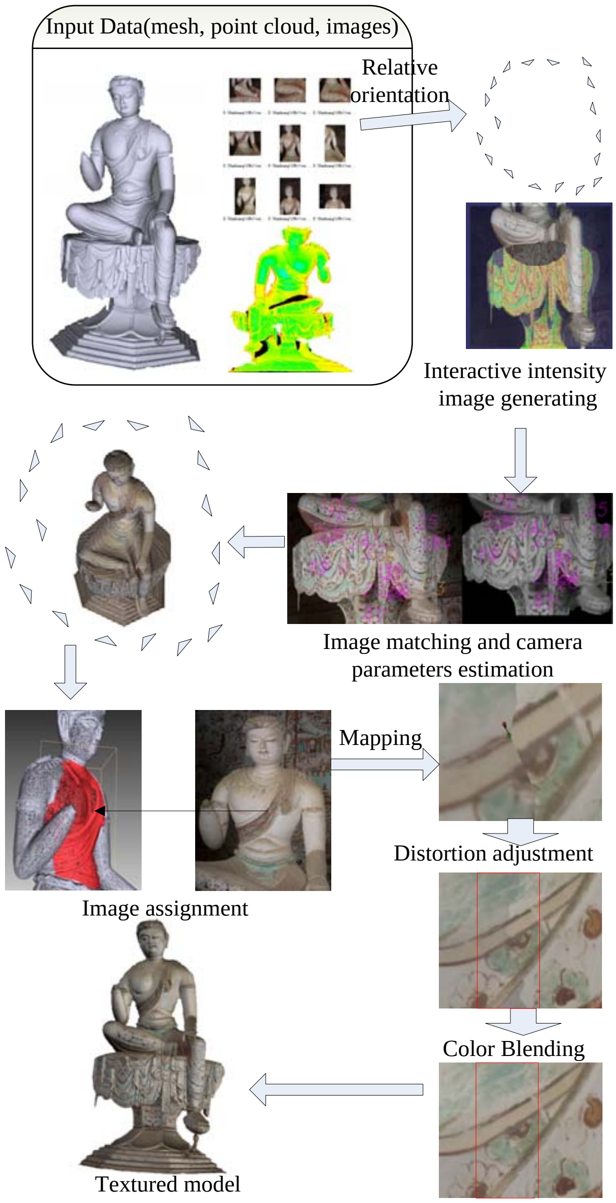

Figure 1. The whole workflow of the texture mapping process. From the input data, the relative model of the texture images can be achieved. After the intensity image generating and the image matching, the camera parameters of most of the images can be figured out. Then, the images can be assigned to the corresponding parts. When mapping images to the mesh, some

local distortion can cause bad effect, a local distortion adjustment is carried out to align the feature of the adjacent images. Finally, colour blending is adopted for the textured model. This workflow stands for the complex mesh case. The nearly planar case is relatively simple. So we don't draw a flowchart.

2.1 Interactive 3D Environment

A 3D rendering environment is constructed to acquire some interaction from the operator. The raw point cloud and the processed triangle mesh can be both displayed under the rendering engine. Particularly, the point cloud was displayed in the pseudo RGB colour generated from the laser echo intensity. The selected photo was displayed in the middle of the window transparently. In that case, the operator can adjust the relative position between the photo and the 3D mesh by changing the position and orientation of 3D mesh to simulate the moment of photography.

2.2 Registration

The registration module contains an intensity image generator and a set of algorithms which are based on the principle of the traditional photogrammetry.
The aim of registration in the paper is calculating the camera parameters of images, using the camera parameters, the vertex of the 3D mesh can be projected on to the image plane to get the corresponding UV coordinate. So, for the purpose of registration, the intensity image generator project the raw point cloud to the image plane to form an intensity image for matching with the optical image. Then, a hybrid matching strategy is taken to match the two kinds of images. RANSAC-based estimation is used to eliminate the matching outliers and figure out the result. The system takes advantage of the relative orientation technology from photogrammetry community to construct the relative space relationship of all the photos. This module can be seen as a pre-processing step of the images, because it's very time consuming. After this step, the images are all registered with the 3D mesh. For the nearly planar mesh, The registration is relatively simple. Firstly, images are emerged into a large image. Then, matching the large images with the intensity image.

2.3 Texture mapping and refinement

Because of the limited FOV of the camera, each image can only cover a part of the mesh. In this part, each image is assigned to a part of the mesh. For various reasons, there are lots of local distortion on the surface. The refining tool can help to fix the local distortion manually.
The seams formed by the light condition difference between images cause awful visualization effect. It's necessary to erase the seams for better result. The multiple resolution spline method (Burt, Adelson, 1983)is adopted to blend the seams away on the 3D mesh.
In the planar mesh case, the matching points of the two images are directly used as control points to do the texture mapping. After mapping, the same refinement procedure should be carried out to get better result.

3. REGISTRATION BETWEEN IMAGES AND MESH

This section describes the registration method between images and the mesh. There are two different mesh cases, one is the mesh with complex structure, and the other one is the nearly planar mesh. The reason is that the DLT algorithm can not work in the planar mesh case. A control point based mapping method is proposed to solve the planar case. The above work will be discussed in detail in this section.

3.1 Mesh with Complex Structure

For mesh with complex structure, in this paper, the DLT algorithm is adopted to get the extrinsic parameters of the image, This is a classic algorithm in the photogrammetry community which used to solve corresponding relationship between the screen coordinate and the 3D point. The subsection describes from the matching point acquiring from the camera parameters parsing in detail.

3.1.1 Intensity Image Generating

For the mesh with complex structure, the DLT algorithm is used to calculate the camera parameters of the images. So, a set of corresponding feature points between image and 3D mesh should be acquired first. During the process from the raw point cloud to triangle mesh, we keep the coordinates of the mesh vertices as original as possible. In order to get the match points between images and 3D mesh, we can get them between images and the raw point cloud instead. So, the echo intensity of the points in the point cloud is used to form an 2d intensity image. The procedure is as follows.
Firstly, the selected image displays transparently in the middle of the 3D window. The image is standstill to the viewpoint of the 3D rendering engine. Secondly, by interactively rotating, moving and scaling the 3D mesh, the operator can get almost the same simulating viewpoint as the picture-taken moment. At this moment, the point cloud can be projected to the image plane to get the screen coordinate. The laser echo intensity is normalized into the grey space. In order to solve the occlusion problem of the point cloud, a Z-buffer technology is carried out. Each point mapped onto the image plane is record. For one image pixel, there may be more than one corresponding 3D points have been record. After projecting, the point nearest to the viewpoint will be kept as the final image pixel. For the almost same viewpoint, the generated intensity image is similar to the original optical image. The corresponding relationship is record between the intensity image pixels and 3D points for the following step.

3.1.2 Image Matching

In this step, the image matching is taken to get the match points between the optical image and the intensity image. Each pixel of the intensity image corresponds to a 3D point in the case that the raw point cloud is dense enough. Our work site is the grottoes. So the scan range is not so long. The laser scanner we use is the Leica HDS6000 which can acquire high resolution point cloud in a short time. So the data can fully meet this requirement.
Each pixel in the intensity image corresponds to a 3D point. So, by a sparse matching the optical image and intensity image, the matching points between optical image and 3D points can be derived. However, the matching suffers from some difficulties. The two types of image are acquired from different sensors. They are different in sampling scale, radiation and etc. Fortunately, the operator assigned the similar view point to the intensity image as the optical image. So, their content is much or less the same. To undertaken the difficulties mentioned above, in this paper, a hybrid and hierarchic matching strategy is adopted. The SIFT image matching strategy is taken to get some matching points from the two image. The k-d tree is adopted to accelerate the image matching process. The SIFT

detector is sensitive to the radiation difference. So some wrong matching point pair may appear. Under this situation, Robust estimation method is needed to eliminate the outliers. In this step, the RANSAC estimation method is adopted to calculate the camera parameters of the image. By this step, the operator can get the simulated image position and orientation of the selected image by a little interaction.

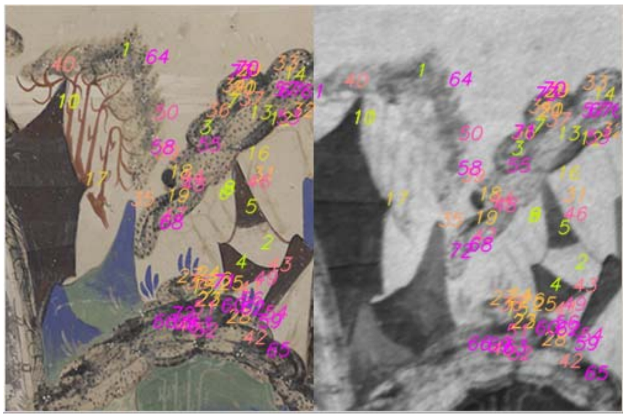

Figure 2. SIFT feature detector is adopted to match the optical image and intensity image. The matching result is shown. Each pixel of the intensity image is related with a 3D point. By the matching, some point pairs between optical image and 3D points are acquired.

3.1.3 Relative Model Reconstruction

In most of the cases, to generate a high resolution textured model, the texture images are in huge amount. It's impractical to get all the images' camera parameters manually. The relative orientation concept from photogrammetry field can be extended to figure out the relative spatial relationship between the images. By this step, most of the images can be located in a relative Euclidian space.

The necessary step of the relative orientation is also the matching between the texture images. For the texture images are often acquired by high resolution camera, the matching process is quite costly. A hybrid matching process is adopted to accelerate the matching speed.

Firstly, an image pyramid is constructed for each image. In this paper, only two level of the pyramid is constructed. Secondly, SIFT matching strategy is used to match the images on top level of the image pyramid. For the top image is quite small, the SIFT matching can process quickly. This matching result will be passed to the original image. Finally, near the detected SIFT feature position, the correlation matching method search the match point with higher precision.

After the matching between texture images, the basic idea of the relative orientation can be carried out to construct the relative spatial relationship between images with overlap.

3.1.4 Absolute Image Pose Location

By above steps, many images have been absolutely orientated and located semi-automatically by the operator. The absolute results should be checked manually by operator to verify the credibility. Because these images have also been included in the relative model generated by last step. By these relative and absolute relationship, all the images in the relative model can be transformed in to the absolute coordinate. In this paper, the camera lens distortion is not taken into account and we consider the laser scanned data as the true value of the object. So the manually oriented result is not so accurate. In order to get a more proper model, a non-linear least square optimization is adopted. After this step, the images are well aligned with the mesh.

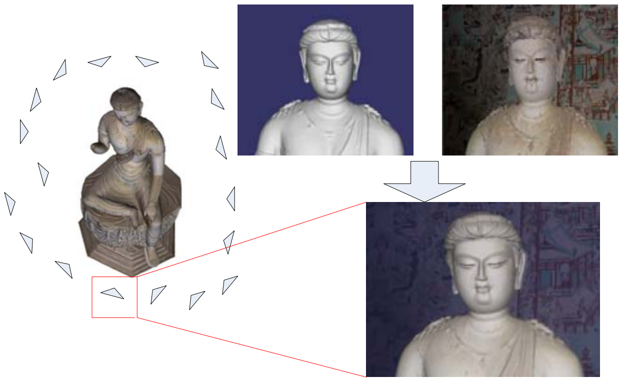

Figure 3. After the absolute image pose location, the images can be aligned well with the model in the interactive 3D display environment with the estimated camera parameters. As shown in the image below, the image displays translucently in front of the model. By this visual way, the images can be mapped to the model efficiently.

3.2 Nearly Planar Mesh

The above registration method adopted can not work in the nearly planar mesh case. Because the DLT can not work in the planar mesh case. In this case, the matching control points based approximating texture mapping method is used.

3.2.1 Image Mosaic and Matching

To keep the high resolution of the image, the pictures are acquired in little pieces. In the nearly planar mesh case, the images can be merged into a large image in the cost of little local distortion. The multiple resolution spline method(Burt, Adelson, 1983) is used to automatically generate the mosaic images. In practice, the merging step is also carried out manually in Photoshop. After rescaling, the large image can be quickly matched with the intensity image. The same matching strategy is adopted in section 3.1.2 to get some matching point pairs.

3.2.2 Control Points Based Texture Mapping

This problem can be regarded as a nearly planar surface parameterization problem. The only thing to do is to supply some corresponding points which we call control points. In this simple situation, a 2D Delaunay triangulation is used to parameterize the nearly planar mesh. Based on the control points, an incremental Delaunay(Lawson, 1977) construction method is carried out. First of all, three points on the mesh and corresponding images are picked by hand. The picked three points can represent a plane which is nearly parallel to the mesh. This step is quite important for the texture mapping is mainly based on this plane. So pick the plane as parallel as the nearly planar mesh. Secondly, depending on the dense control points acquired in the last step, the image can be directly mapped onto the nearly planar mesh. However, when the matching step can not give a good distribution of the control points, a user interface is also supplied to get the corresponding points manually. The manual work is inevitable because of the need of the precise control of the boundary area. After the simple parameterization, the UV coordinate of the vertex on the mesh can be interpolated in the local triangles generated from the control points. As shown in Fig4. The mapping result is shown in the image below. Finally, the local distortion depends mainly on the density and the precision of the control points.

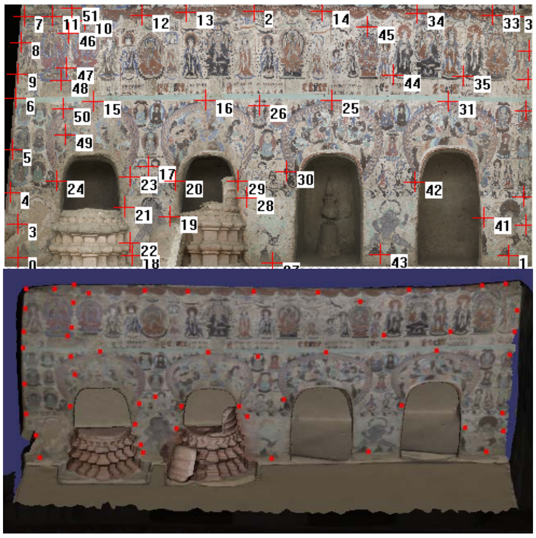

Figure 4. The texture mapping of wall in the NO.285 cave of Dunhuang Mogao grottoes. The top image shows the control points distribution. The density of control points in the boundary of the wall is larger than the middle. The bottom image give a texture mapping result of the planar mesh.

4. TEXTURE MAPPING AND REFINEMENT

4.1 Image assignment

In the complex mesh case, although the images are aligned with the 3D mesh, the images are not sure which place to cover on the mesh. The principle of assigning images to the which part of the mesh is as follows. First of all, a virtual ray emitted from the centre of the image, which intersect with the mesh. Then based on the intersected triangle, a smooth constraint region growing methods(Rabbani, van den Heuvel et al., 2006) is employed to segment the mesh into patched and assigned to the right images. Under some situation that the mesh is quite complex, the automatic segmentation can not assign images properly, the semi-automatic way of image assigning is also supported in our system. The operator can interactively delete the blur area of texture caused by over covering of one image. This step can be performed quite well by combing the automatic and semi-automatic way.

4.2 Local Distortion Adjustment

The data acquiring period brought various errors. Such as the physics error of laser scanner, camera calibration error , condition caused error and etc. The inevitable errors cause the discontinuity of the transition areas of adjacent mesh mapped with different texture images. As shown in the left image of Fig6. To solve this problem, a manually local distortion adjustment method is implemented to get better visualization effect. An interactive local UV coordinate adjustment is carried out to align the features on the different images. First of all, an influencing radius is set to limit the UV displacement space. The adjustment is limited in this sphere. This threshold can largely reduce the degeneration of the images caused by the UV adjustment. Then, based on the input of the operator, the UV can be adjusted. The adjustment result is shown in the right image. This work is useful but quite time consuming. Some job will be done to reduce the human interaction.

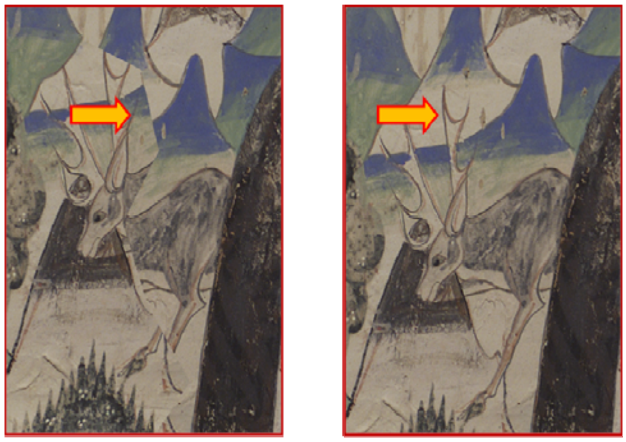

Figure 5. The local distortion is explicitly pointed out by the yellow arrow in the left image above. After manually adjustment, the features between the two adjacent images can be aligned. As shown in the right image.

4.3 Colour Blending

Due to the different light condition, the texture images are different in hue and saturation and etc. When the images are mapped onto corresponding parts of the mesh, a seam will appear between the two images on the mesh, as shown in the left image in Fig6**.** To address this problem, the multiple resolution spline blending method mentioned in (Burt, Adelson, 1983) is adopted. This method present a flexible transition zone based blending strategy which is extracted from the perception habit of human. The low frequency information is blended in a relative wide zone and the high frequency in a narrow zone. The blending result can be seen in right image of Fig6.

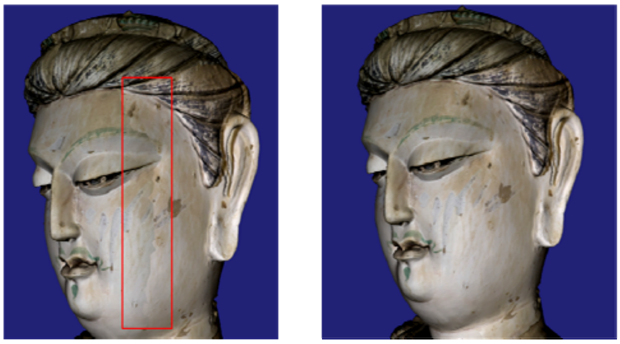

Figure 6. Adjacent images under different light conditions lead to explicit seams. As shown in the red rectangle in the left image. Multiple resolution spline blending can erase the seams. The blending result can be seen in the right image.

5. CONCLUSION AND FUTURE WORK

A texture mapping system was introduced in this paper, including two kinds of texture mapping methods which can handle two different conditions. The two different methods can meet most of the requirements in the digitalization of the cultural heritage. The underlying principle of the method for the complex mesh is from traditional photogrammetry. The usage of the 3D visualization environment makes a direct impression of the texture mapping process, thus improve the efficiency of the process. The combination of automatic and semi-automatic way does really work in various complex situation. This system can work well and efficiently in the 3D digital reconstruction of Dunhuang Mogao grottoes.

However, there are aspects which can be improved in the future. Firstly, the camera calibration can be added to the process to achieve higher precision. Secondly, the registration procedure in this paper between images and mesh is based on a rigid model. However, the real model between the images and mesh is actually non-rigid. The non-rigid registration is a future research topic. Thirdly, there are lots of errors from all kinds of factors. Eliminating and distributing these errors by a reasonable way is an valuable problem. Though the images are stored as texture, some content of the image is invalid for texture mapping. Building a texture atlas automatically from the images can largely reduce the size of the textured model. This work will be done in the future.

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