3D MODELING OF SMALL ANTIQUE BASED ON THE PROJECTOR-CAMERA SYSTEM

Jun Tao [a, *], Zuxun Zhang [a], Jianqing Zhang [a]

[a] Wuhan University, College of Remote Sensing and Information Engineering, 129 Luoyu Road, Wuhan, Hubei, P.R.China, martintao@etang.com, zxzhang@supresoft.com.cn, Jqzhang@supresoft.com.cn

KEY WORDS: 3D Modeling, Antique, Digital Camera, Projector, Close-Range Photogrammetry

ABSTRACT:

The paper proposes a flexible and practical method to 3D model the antique based on the projector-camera system. The projector-camera system is composed of a slide projector, a digital camera, a control ground and a computer. The computer controls other three equipments working together automatically and efficiently. The control ground is a planar grid on the centre of a rotating platform. According to the size of the planar grid, the target antique is relatively small. The planar grid is functioned as the calibration of the slide projector and the digital camera. After calibrated respectively in advance, the projector-camera system is similar with the binocular vision system in the principle of 3D reconstruction. The digital camera takes two images of small antique with the projected texture characteristic and without it at one time. The two sequential images are taken from the different orientations. 3D coordinates of the space feature point can be computed by the space forward intersection. Using the whole adjustment, 3D coordinates of all space points projected on the whole surface of the target small antique from the different orientations can be worked out accurately. 3D model of the target small antique is acquired by connecting all neighbor space feature points and the real texture is rendered from relative images without the projected texture characteristic. 3D modeling of small antique is achieved entirely and finally. 3D modeling of small antique proposed in the paper is confirmed to be correct and effective completely by the results of the modeling experiments.

1. INTRODUCTION

1.1 Antique Digitalization

The antique is expensive and rare and belongs to a kind of the cultural relics. With the development of computer skill and the demand of age, the digitalization of the antique is a popular and excellent approach in the field of the cultural relics protection. At present, 3D modeling of the antique is a huge and current challenge to the antique digitalization. 3D modeling of the antique is asked to be untouched because it is friable and fragile. So the methods of close-range photogrammetry is very suitable and applied because the untouchability is the obvious characteristic of close-range photogrammetry. The real texture of the antique is obscure and unclear because of the long time so that it is difficult to be extracted out and matched correctly. The projector can project the texture characteristic onto the surface of the antique in order to resolve this trouble. The paper proposes a flexible and practical method to 3D model the antique based on the projector-camera system.

1.2 3D Modeling

3D modeling is referred as a process of the recovery of three-dimensional model from the two-dimensional digital camera images. During the image formation process of the camera, explicit 3D information about the scene or objects in the scene is lost. Therefore, 3D model or depth information has to be inferred implicitly from the 2D intensity images. The key of the traditional method lies in the matching of the corresponding features in the images. When there is no feature or lack of feature in the objects, or when the features cannot be matched correctly at all, the main problems appear in the process of the 3D modelling.

Antique is just lack of the real texture on its surface. The paper provides a method to resolve the problems above. It is an ordinary slide projector that can supply any feature what you want to the target antique. These features are easy to be controlled and to be extracted out, which has paved the convenient path for the matching of them. According to the demand and real condition, the features can be changed or adjusted.

The paper explains clearly how to use the ordinary slide projector and how to apply it to the applications of the 3D modeling, too.

1.3 Overview of the Paper

The paper proposes a flexible and practical method to 3D model the antique based on the projector-camera system. The projector-camera system is composed of a slide projector, a digital camera, a control ground and a computer. The computer controls the other three equipments working together automatically and efficiently. The control ground is a planar grid on the centre of a rotating platform.

According to the size of the planar grid, the target antique is relatively small. The planar grid is functioned as the calibration of the slide projector and the digital camera. After calibrated respectively in advance, the projector-camera system is similar

* Corresponding author, E_mail: martintao@etang.com, martintao@tom.com; Tel: +86-27-87664509, 87654319.

with the binocular vision system in the principle of 3D reconstruction.
When the slide projector projects the designed texture characteristic onto the surface of the small antique, the digital camera takes two images of the small antique with the projected texture characteristic and without it at one time. The two sequential images are taken from the different orientations when the rotating platform rotates continually. For each space feature point projected on the surface of the target small antique, there are two corresponding 2D points existing. One is an image point in one of the image sequences from the digital camera and another is a point in the slide from the projector. Using the image processing method, the image point can be extracted out accurately so that its 2D coordinates are gained. At the same time, the slide point is designed first so that its 2D coordinates are calculated by the known data. The 3D coordinates of the space feature point can be computed by the space forward intersection.

Using the whole adjustment, the 3D coordinates of all space points projected on the whole surface of the target small antique from the different orientations can be worked out accurately. The 3D model of the target small antique is acquired by connecting all neighbor space feature points and the real texture is rendered from relative images without the projected texture characteristic.

The 3D modeling of small antique is achieved entirely and finally. The 3D modeling of small antique proposed in the paper is confirmed to be correct and effective completely by the results of the modeling experiments.

2. METHODOLOGY AND ALGORITHM

2.1 System Equipments

The projector-camera system is composed of a slide projector, a digital camera, a control ground and a computer. The computer controls the other three equipments working together automatically and efficiently. The control ground is a planar grid on a rotating platform. The planar grid is functioned as the calibration of the slide projector and the digital camera. After calibrated respectively in advance, the projector-camera system is similar with the binocular vision system on the principle of 3D reconstruction.

2.1.1 The Calibration of the Digital Camera: The digital camera needs to be calibrated in advance, because the late computation of the coordinates of the space feature requires the intrinsic and extrinsic parameters of the digital camera. Therefore, the calibration of the digital camera is an important preceding step.

Direct Linear Transformation (DLT) is a well-known method used in close-range photogrammetry because of it's no need for initial value of camera intrinsic and extrinsic parameters. The existed camera calibration techniques are studied thoroughly. The restricting condition among 2D-DLT parameters is worked out using the correspondence of collinear equation and 2D-DLT. The decomposition of initial values of camera intrinsic and extrinsic parameters using 2D-DLT is detailed. Planar-scene camera calibration algorithm with collinear equations is addressed. So the calibration of the digital camera is accomplished entirely and the intrinsic and extrinsic parameters of the digital camera are ready to be used in the future. (Zhang Zhengyou, 1998; Zuxun Zhang, and Yongjun Zhang, 2002.)

If the camera is not an ordinary one but a special digital measuring-camera, the calibration could be cancelled because the intrinsic parameters of the digital camera can be gotten as the known data. However, the extrinsic parameters of the digital camera are still required to calculated out first.

2.1.2 The Calibration of the Ordinary Projector: In this approach proposed in the paper, the slide projector makes the same function as a digital camera. So the ordinary slide projector also desires to be calibrated in advance. Its intrinsic and extrinsic parameters are also applied to the computation process.

The algorithm with 2D direct linear transformation (2D-DLT) and collinear equations is used to calibrate the projector. The algorithm is addressed systematically and entirely as following. First, the image coordinates of the projector are designed carefully and the space coordinates of the projector are computed by the image data and the intrinsic and extrinsic parameters of the digital camera. Then, the decomposition of initial values of the projector intrinsic and extrinsic parameters using the correspondence of 2D-DLT and collinear equation is deduced. Finally, the projector calibration parameters are worked out by the whole adjustment. By this time, the intrinsic and extrinsic parameters of the ordinary slide projector are ready to be used in the next program. (Jianqing Zhang, Jun Tao, Zuxun Zhang, 2003; Jun Tao, Jianqing Zhang, and Zuxun Zhang, 2004.)

2.2 Steps of the Method

The slide projector can project the texture characteristic onto the surface of the antique maybe lack of or without real texture suitable for matching. The digital camera takes sequential images of the antique with the projected texture characteristic. The images are taken from the different orientations when the rotating platform rotates continually.

For each space feature point projected on the surface of the antique, there are two corresponding 2D points existing. One is an image point in one of the image sequences from the digital camera and another is a point in the slide from the projector. Using the image processing method, the image point can be extracted out accurately so that its 2D coordinates are gained. At the same time, the slide point is designed first so that its 2D coordinates are calculated by the known data. The 3D coordinates of the space feature point projected can be computed by the space forward intersection.

Using the correspondence of whole adjustment and the inherent structure characteristic of the solid of revolution, the 3D coordinates of all space points projected on the whole surface of the antique can be computed out entirely and accurately. The 3D model of the antique is acquired by connecting all neighbor space points.

2.3 Algorithm

The collinear equations are: (Zuxun Zhang, and Jianqing Zhang, 2000; Zhizhuo Wang, 1990; Deren Li, 1992; Wenhao Feng, 2002.)

$$x - x_0 = -f\frac{a_1(X-X_s)+b_1(Y-Y_s)+c_1(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)}$$
$$y - y_0 = -f\frac{a_2(X-X_s)+b_2(Y-Y_s)+c_2(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)} \quad (1)$$

where x_0, y_0, f = the intrinsic parameters of the projector

X_S, Y_S, Z_S = the coordinates of the projector centre

X, Y, Z = the space coordinates of points

x, y = the image coordinates of the relative points

$R = \{a_i, b_i, c_i, i = 1,2,3\}$ = the rotated matrix made up of rotated angles ϕ, ω, κ

To the planar grid, the coordinates $Z = 0$

There are four equations listed ordinarily according to a pair of homologous points. However, the space coordinates (X, Y, Z) can be calculated out only by three equations. Through the line matching based on the structure illumination, there exist three known equations shown in the Figure.1.

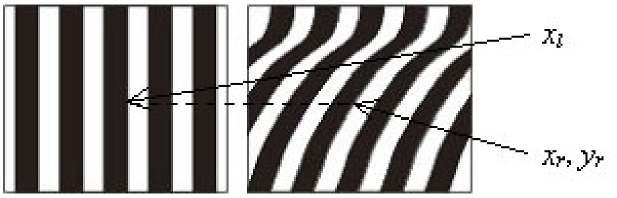


Figure 1. The line match based on the structure illumination

There is one point on the curve of the image taken by the digital camera, and its coordinates are x = x_r, y = y_r. from the formula (1), then:

$$[a_3+f_r\frac{a_1}{(x_r-x_{r0})}]X+[b_3+f_r\frac{b_1}{(x_r-x_{r0})}]Y+[c_3+f_r\frac{c_1}{(x_r-x_{r0})}]Z=$$
$$[a_3+f_r\frac{a_1}{(x_r-x_{r0})}]X_{rs}+[b_3+f_r\frac{b_1}{(x_r-x_{r0})}]Y_{rs}+[c_3+f_r\frac{c_1}{(x_r-x_{r0})}]Z_{rs} \quad (2)$$
$$[a_3+f_r\frac{a_2}{(y_r-y_{r0})}]X+[b_3+f_r\frac{b_2}{(y_r-y_{r0})}]Y+[c_3+f_r\frac{c_2}{(y_r-y_{r0})}]Z=$$
$$[a_3+f_r\frac{a_2}{(y_r-y_{r0})}]X_{rs}+[b_3+f_r\frac{b_2}{(y_r-y_{r0})}]Y_{rs}+[c_3+f_r\frac{c_2}{(y_r-y_{r0})}]Z_{rs}$$

There is a corresponding line in the projected slide according to the point on the curve of the image taken by the digital camera and its equation is x = xl. From the formula (1), then:

$$[a_6+f_l\frac{a_4}{(x_l-x_{l0})}]X+[b_6+f_l\frac{b_4}{(x_l-x_{l0})}]Y+[c_6+f_l\frac{c_4}{(x_l-x_{l0})}]Z=$$
$$[a_6+f_l\frac{a_4}{(x_l-x_{l0})}]X_{ls}+[b_6+f_l\frac{b_4}{(x_l-x_{l0})}]Y_{ls}+[c_6+f_l\frac{c_4}{(x_l-x_{l0})}]Z_{ls} \quad (3)$$

From the formula (2) and (3), then:

$$\begin{cases} X=\dfrac{\begin{vmatrix} [a_3+f_r\frac{a_1}{(x_r-x_{r0})}]X_{rs}+[b_3+f_r\frac{b_1}{(x_r-x_{r0})}]Y_{rs}+[c_3+f_r\frac{c_1}{(x_r-x_{r0})}]Z_{rs} & [b_3+f_r\frac{b_1}{(x_r-x_{r0})}] & [c_3+f_r\frac{c_1}{(x_r-x_{r0})}] \\ [a_3+f_r\frac{a_2}{(y_r-y_{r0})}]X_{rs}+[b_3+f_r\frac{b_2}{(y_r-y_{r0})}]Y_{rs}+[c_3+f_r\frac{c_2}{(y_r-y_{r0})}]Z_{rs} & [b_3+f_r\frac{b_2}{(y_r-y_{r0})}] & [c_3+f_r\frac{c_2}{(y_r-y_{r0})}] \\ [a_6+f_l\frac{a_4}{(x_l-x_{l0})}]X_{ls}+[b_6+f_l\frac{b_4}{(x_l-x_{l0})}]Y_{ls}+[c_6+f_l\frac{c_4}{(x_l-x_{l0})}]Z_{ls} & [b_6+f_l\frac{b_4}{(x_l-x_{l0})}] & [c_6+f_l\frac{c_4}{(x_l-x_{l0})}] \end{vmatrix}}{\Delta} \\ Y=\dfrac{\begin{vmatrix} [a_3+f_r\frac{a_1}{(x_r-x_{r0})}] & [a_3+f_r\frac{a_1}{(x_r-x_{r0})}]X_{rs}+[b_3+f_r\frac{b_1}{(x_r-x_{r0})}]Y_{rs}+[c_3+f_r\frac{c_1}{(x_r-x_{r0})}]Z_{rs} & [c_3+f_r\frac{c_1}{(x_r-x_{r0})}] \\ [a_3+f_r\frac{a_2}{(y_r-y_{r0})}] & [a_3+f_r\frac{a_2}{(y_r-y_{r0})}]X_{rs}+[b_3+f_r\frac{b_2}{(y_r-y_{r0})}]Y_{rs}+[c_3+f_r\frac{c_2}{(y_r-y_{r0})}]Z_{rs} & [c_3+f_r\frac{c_2}{(y_r-y_{r0})}] \\ [a_6+f_l\frac{a_4}{(x_l-x_{l0})}] & [a_6+f_l\frac{a_4}{(x_l-x_{l0})}]X_{ls}+[b_6+f_l\frac{b_4}{(x_l-x_{l0})}]Y_{ls}+[c_6+f_l\frac{c_4}{(x_l-x_{l0})}]Z_{ls} & [c_6+f_l\frac{c_4}{(x_l-x_{l0})}] \end{vmatrix}}{\Delta} \\ Z=\dfrac{\begin{vmatrix} [a_3+f_r\frac{a_1}{(x_r-x_{r0})}] & [b_3+f_r\frac{b_1}{(x_r-x_{r0})}] & [a_3+f_r\frac{a_1}{(x_r-x_{r0})}]X_{rs}+[b_3+f_r\frac{b_1}{(x_r-x_{r0})}]Y_{rs}+[c_3+f_r\frac{c_1}{(x_r-x_{r0})}]Z_{rs} \\ [a_3+f_r\frac{a_2}{(y_r-y_{r0})}] & [b_3+f_r\frac{b_2}{(y_r-y_{r0})}] & [a_3+f_r\frac{a_2}{(y_r-y_{r0})}]X_{rs}+[b_3+f_r\frac{b_2}{(y_r-y_{r0})}]Y_{rs}+[c_3+f_r\frac{c_2}{(y_r-y_{r0})}]Z_{rs} \\ [a_6+f_l\frac{a_4}{(x_l-x_{l0})}] & [b_6+f_l\frac{b_4}{(x_l-x_{l0})}] & [a_6+f_l\frac{a_4}{(x_l-x_{l0})}]X_{ls}+[b_6+f_l\frac{b_4}{(x_l-x_{l0})}]Y_{ls}+[c_6+f_l\frac{c_4}{(x_l-x_{l0})}]Z_{ls} \end{vmatrix}}{\Delta} \end{cases}$$

where

$$\Delta = \begin{vmatrix} [a_3+f_r\frac{a_1}{(x_r-x_{r0})}] & [b_3+f_r\frac{b_1}{(x_r-x_{r0})}] & [c_3+f_r\frac{c_1}{(x_r-x_{r0})}] \\ [a_3+f_r\frac{a_2}{(y_r-y_{r0})}] & [b_3+f_r\frac{b_2}{(y_r-y_{r0})}] & [c_3+f_r\frac{c_2}{(y_r-y_{r0})}] \\ [a_6+f_l\frac{a_4}{(x_l-x_{l0})}] & [b_6+f_l\frac{b_4}{(x_l-x_{l0})}] & [c_6+f_l\frac{c_4}{(x_l-x_{l0})}] \end{vmatrix}$$

At present, the space coordinates (X, Y, Z) have been calculated out already.

All antique are almost belonged to the solid of revolution. According to the inherent structure characteristic of the solid of revolution, every section of it parallel with horizontal surface is vertical with its fixed axis. The section is just a circle. Considering to the same coordinates of the centre of circle in the every horizontal section, the formula (4) is from the two different horizontal sections. For example, one is from the top horizontal section of the solid of revolution and another is from the bottom horizontal section of the solid of revolution. Then:

$$-2(x_1-x_2)x_0-2(y_1-y_2)y_0-R_1^2+R_2^2+$$
$$(x_1^2-x_2^2+y_1^2-y_2^2)=0 \quad (4)$$

where x_0, y_0 = the coordinates of the centre of the circle.

x_i, y_i = the coordinates of the points on the circle i

R_i = the radius of the circle i

From the formula (4), the equation of the whole adjustment is:

$$X = (A^T A)^{-1} A^T L \tag{5}$$

where:

$$A = \begin{vmatrix} -2(x_{11} - x_{21}) & -2(y_{11} - y_{21}) & -1 & 1 \\ -2(x_{11} - x_{22}) & -2(y_{11} - y_{22}) & -1 & 1 \\ \ldots\ldots & \ldots\ldots & .. & .. \\ -2(x_{1i} - x_{2j}) & -2(y_{1i} - y_{2j}) & -1 & 1 \\ \ldots\ldots & \ldots\ldots & .. & .. \\ -2(x_{1m} - x_{2(n-1)}) & -2(y_{1m} - y_{2(n-1)}) & -1 & 1 \\ -2(x_{1m} - x_{2n}) & -2(y_{1m} - y_{2n}) & -1 & 1 \end{vmatrix}$$

$$L = \begin{vmatrix} x_{11}^{\;2} - x_{12}^{\;2} + y_{11}^{\;2} - y_{21}^{\;2} \\ x_{11}^{\;2} - x_{22}^{\;2} + y_{11}^{\;2} - y_{22}^{\;2} \\ \ldots\ldots \\ x_{1i}^{\;2} - x_{2j}^{\;2} + y_{1i}^{\;2} - y_{2j}^{\;2} \\ \ldots\ldots \\ x_{1m}^{\;2} - x_{2(n-1)}^{\;2} + y_{1m}^{\;2} - y_{2(n-1)}^{\;2} \\ x_{1m}^{\;2} - x_{2n}^{\;2} + y_{1m}^{\;2} - y_{2n}^{\;2} \end{vmatrix}$$

$$X = \begin{vmatrix} x_0 \\ y_0 \\ R_1^{\;2} \\ R_2^{\;2} \end{vmatrix}$$

After resolving the X, the coordinates of the fixed axis of the solid of revolution can be worked out obviously. At the same time the distance from the every space point projected on the surface of the antique to its fixed axis can be computed out by the horizontal circle formula.

3. DATA AND EXPERIMANTAL RESULTS

3.1 Design Data

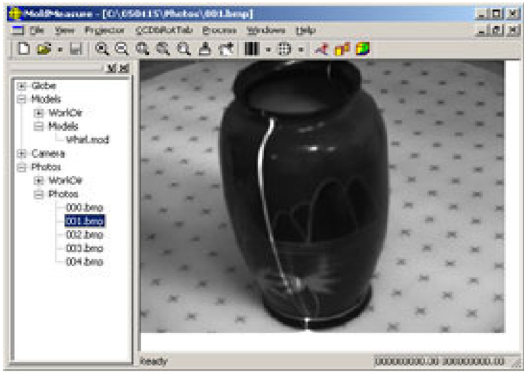
The size of the rotating platform is 60cm×60cm. A planar grid is fixed upon it, which supplies the controlling points and the coordinates system. There are 18×18=324 controlling points in the planar grid. The interval of these points is the same and is 30mm. Each point has its own serial number which is exclusive. By using the coordinates of these points, the digital camera and the slide projector can be calibrated correctly and the extrinsic parameters of both are also calculated out entirely.

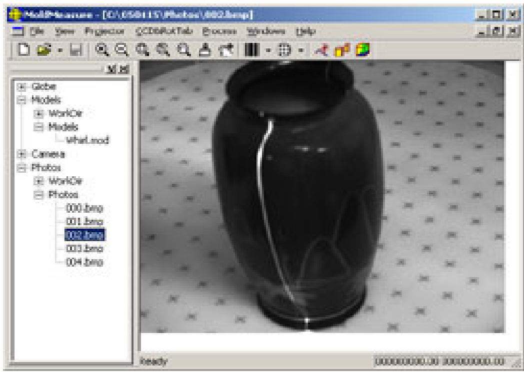
The size of the feature slide designed is 1024 pixels×768 pixels. The texture feature is designed as a line which is better to show the edge of the antique. The line is white with the ground of black and is located in the centre of the slide.

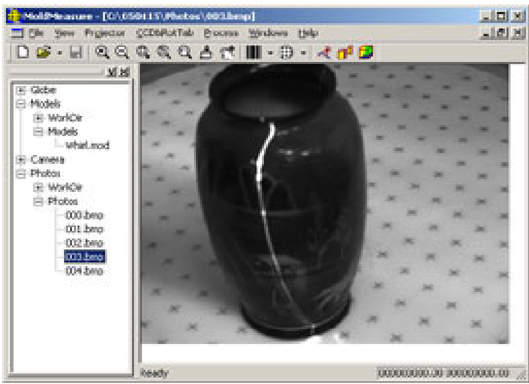
3.2 Image Sequences

When the positions of the camera and the projector are adjusted well and fixed relatively, both need to be focused respectively. The distance from the digital camera to the rotating platform is about 0.8 meters and the distance from the slide projector to the rotating platform is about 1.5 meters.

The target antique is an ancient vase. Then the ancient vase is put on the centre of the rotating platform. The slide projector projects the line in the slide onto the surface of the vase. It is ascertained that the projected line is through the whole body of the vase, which is very important and necessary. Then the camera is used to take sequential images of the ancient vase with the slide projector illuminating when the rotating platform rotates continually. In the experiment the camera takes images from 4 orientations and there are 4 images in total as the image data shown in the Figure 2. The size of each image is 1300pixels×1030pixels.







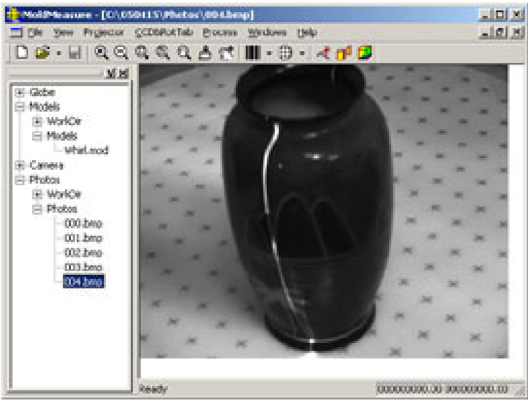
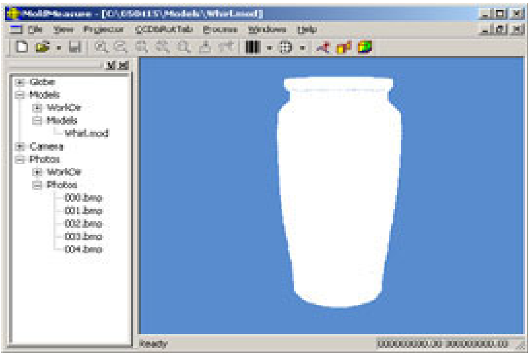


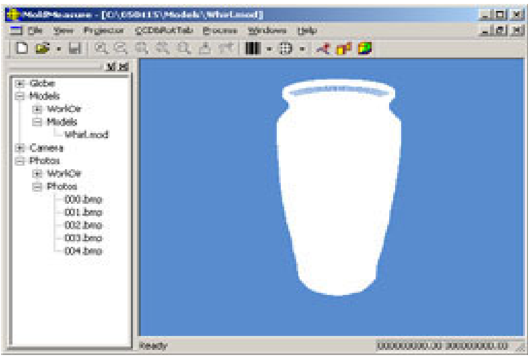
Figure 2. The sequential images with the feature

3.3 Experimental Results

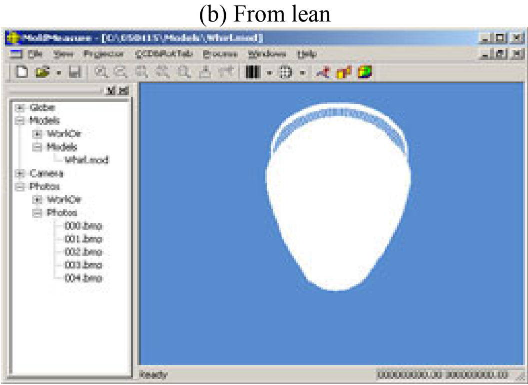
The whole model of the ancient vase is made up of many levels of the circles. The view of the final model is shown in the Figure 3.



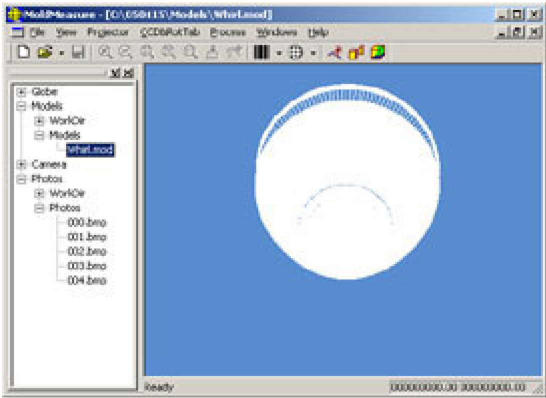
(a) From side



(b) From lean



(c) From lean



(d) From top

Figure 3. The model of the ancient vase

4. CONCLUSIONS

4.1 Achievements of the Paper

The approach proposed in the paper is confirmed to be proper and applicable from the results of the experimental data. This approach only requires a digital camera, an ordinary slide projector and a rotating platform. These equipments are easy to be ready for the applications.

The paper also deduces the detail algorithm of this approach which is understandable and relatively simple. Using the algorithm provided, the correct model results can be gotten from the image data. To sum up, the approach with this algorithm is effective and effectual.

According to the size of the antique, the distance of the slide projector from the rotating platform and the density of the feature in the slide can be changed and adjusted, so that this approach is suitable for many kinds of applications. Moreover, it is hardly affected by the space factor or time factor. The approach provided by the paper is flexible and practical.

4.2 Limitations and Future Work

Because of the tight time and the restricted experimental environment, there are a few limitations appearing in this approach.

- The reflection of the projecting light from the target antique is complex and variable with different colour or material of the antique. If the reflection is not clear or is more than one, it would happen that the extraction of the feature becomes difficult or is reduplicate. So the reflection from the antique need be good enough.

- The experimental results of the model is not added the real texture. So the collection of the real texture of the target antique is demanded. Then the real texture should add to the model.

- The experimental target of the paper aims at only the antique whose main body is the simple solid of rotation. So the approach and the algorithm need to be consummated and meliorated for applying to the complex antiques.

To these limitations above, the future work that will be done is as following.

- The feature projected should be designed carefully and in detailed according to the different target antique. It is its size, its shape, its colour, its brightness and so on that should be considered entirely. It is a trial and error procedure.
- The 3D model of the antique is acquired by the image data and the texture is achieved form relative images with no projected feature.
- The 3D modelling of the complex target antique is divided into two main steps. The main body of the target antique is reconstructed first as a solid of rotation. Then, affiliation of the target antique is located onto the model of the main body. The latter is the key work of the next.

To sum up, the future work is put forward for the next research on the basis of the approach and the algorithm proposed by the paper.

REFERENCES

Feng Wenhao, 2002. *Close-Range Photogrammetry*, Wuhan University Press, Wuhan, China.

Li Deren, 1992. *Analytical Photogrammetry*, Wuhan University Press, Wuhan, China, pp. 26-33, pp. 59-61.

Tao Jun, Jianqing Zhang, and Zuxun Zhang, 2004. *Calibration of a Projector with a Planar Grid*, ISPRS, Istanbul, Turkey.

Wang Zhizhuo, 1990. *Principles of Photogrammetry*, Surveying and Mapping Press, Beijing, China.

Zhang Jianqing, Jun Tao, Zuxun Zhang, 2003. A flexible technique for the slide projector calibration, *Proceedings of SPIE - The International Society for Optical Engineering*, Beijing, China, v 5286, n 1, pp. 187-190.

Zhang Zhengyou, 1998. *A Flexible New Technique for Camera Calibration*, Technical Report, Microsoft Research, Redmond, WA 98052, USA.

Zhang Zuxun, and Jianqing Zhang, 2000. *Digital Photogrammetry*, Wuhan University Press, Wuhan, China, pp. 112-115.

Zhang Zuxun, and Yongjun Zhang, 2002. Digital Camera Calibration Using 2D-DLT And Collinear Equation With Planar Scenes (in Chinese), *Geomatics and Information of Wuhan University*, 27(6), Wuhan, China.