THREE-DIMENSIONAL MEASUREMENT OF THE BROKEN PIECES OF RELICS

Ichiroh KANAYA, Yuko KANEMOTO, Kunihiro CHIHARA*
*Professor, Graduate School of Information Science, Nara Institute of Science and Technology
8916-5 Takayama-cho Ikoma Nara 630-0101 JAPAN
E-mail: {itirou-k, yuuko-k, chihara}@is.aist-nara.ac.jp

Qian CHEN
Assistant Professor, Faculty of System Engineering, Wakayama University
930 Sakaedani Wakayama 640-8510 JAPAN
E-mail: chen@sys.wakayama-u.ac.jp

Commission V, Working Group 5

KEYWORDS: Information Archaeology, Object Modeling, 3D Measurement, View Integration, Relic Shard

ABSTRACT

This article describes a new approach to build three-dimensional models of the broken pieces of relics, which aims to make realistic relic models on computers for archaeological use. The shapes of the front face and the back face of a broken piece are first digitized with a laser range finder. Then these front and back face shapes are attached each other to reconstruct the original three-dimensional shape of the relic shard. Texture mapping is also done on the virtually reconstructed relic shard (virtual relic). The texture image is taken by a 3CCD digital video camera. We examined these reconstruction methods for several relics. The reconstructed virtual relics were enough accurate and realistic for archaeological use.

1. INTRODUCTION

Relics have the nature of change in quality when they are excavated from ruins and then exposed under air or sunlight. Thus some methods are required to record or preserve the archaeological properties.

Conventionally sketches and photographs have been widely used for preserving such archaeological properties. In this method, however, a large number of photographs of a relic from various angles are required to record the three-dimensional shape data of the single relic.

There are another problems on preserving broken relics like earthenware shards. Excavated broken earthenware should be restored from the shards of them, but sketches or photographs cannot be used for restoration.

To solve these problems, computer-based modeling methods of relics are researched with contributions from three-dimensional measurement and computer graphics research [Kanaya 1997, Watanabe 1997]. However, there are still some problems in terms of archaeological use.

One major problem in the conventional research is in method of obtaining three-dimensional shape data of relic shards. Conventional research that uses a laser range finder has a weak point on the reality of the virtual relic. Another research that uses MRI equipment to obtain three-dimensional shape of relics has another weak point. MRI is relatively harder to operate with than laser range finders, while the MRI method has an advantage on the accuracy of reconstructed virtual relics when it is compared to the former method.

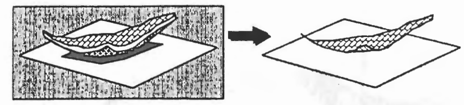
We propose a new method of three-dimensional modeling of a relic shard that achieves enough accuracy and efficiency. By our approach, a single relic shard is scanned by laser range finder twice, front face and back face. And then the two shape data of front and back face are integrated using physical constraint of the shard shape.

2. 3D MODELING OF RELIC SHARDS

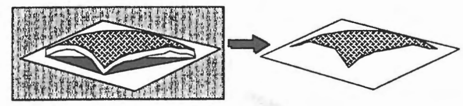
For reconstructing three-dimensional model of a relic shard, we first measure the shape of the front face and the back face of the relic independently, and then integrate the two shapes so that we achieve a complete three-dimensional modeling of the shard. Each surface of the shard is scanned by a laser range finder, which is kind of three-dimensional surface measurement equipment.

The basic idea to integrate front face and back face of a relic shard is as follows. The front and the back surface of a shard should be integrated with a proper coordinate transformation. The points of the back face of the shard that touch the horizontal plane where the piece is put on when measuring the shape of its front face are determined from digitized back face surface. Once these ground-contact points are determined, the coordinate space relation is determined.

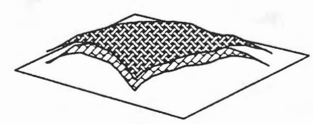
Next the shape data of the front face and the back face are merged using that coordinate transformation. We perform another transformation of the front face model so that both front and back surface model share a same Z-axis coordinate. After Z-axis matching, the gravity center and the inertia should be adjusted each other. For this purpose, we performed another mathematical transformation of the front surface model (fig. 1).



(a) Measurement of 3D shape of back face



(b) Measurement of 3D shape of front face



(c) Reconstruction of model of whole shard

Fig. 1: Measurement of 3D shape of relic and reconstruction of its model

2.1 3D Measurement of Relic Shard

Three-dimensional shape of front face and back face of a relic shard are measured using laser range finder. We defined that the back face of a shard is the side to which touches ground plane when the shard is put on the ground with stable position.

2.2 Surface Integration

To integrate the front face shape data and the back face shape data of the relic shard, the front face data is transformed and then the two-dimensional Affine transformation is performed as follows.

Process 1

Ground plane of a relic shard is estimated. The ground plane is the plane that contains the points on the back surface of the shard on which touch the ground (fig. 2a-c).

Process 2

Coordinate transformation for the agreement with the ground plane and the ground surface is calculated. Let T be the matrix for this coordinate transformation. The transformation T is performed on the back face surface model so that the Z-axis of the back surface model agrees with Z-axis of the front one (fig. 2d).

Process 3

Two-dimensional Affine transformation is performed on the front surface model to make its position and direction agree with the position and direction of the back surface model. The gravity center and inertia axis of the projection of the back surface model to X-Y plane are used to determine the Affine transformation factor.

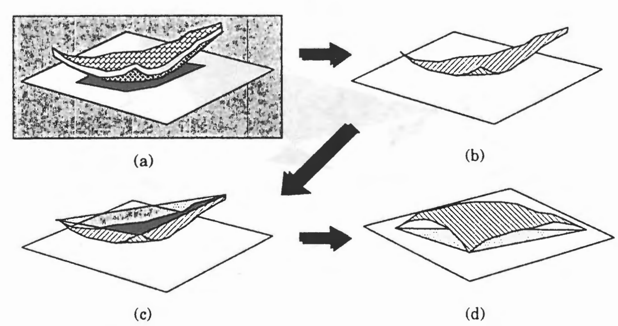


Fig. 2: Transformation of back surface shape data

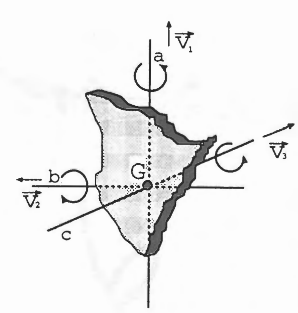


Fig. 3: Gravity center and inertial axis

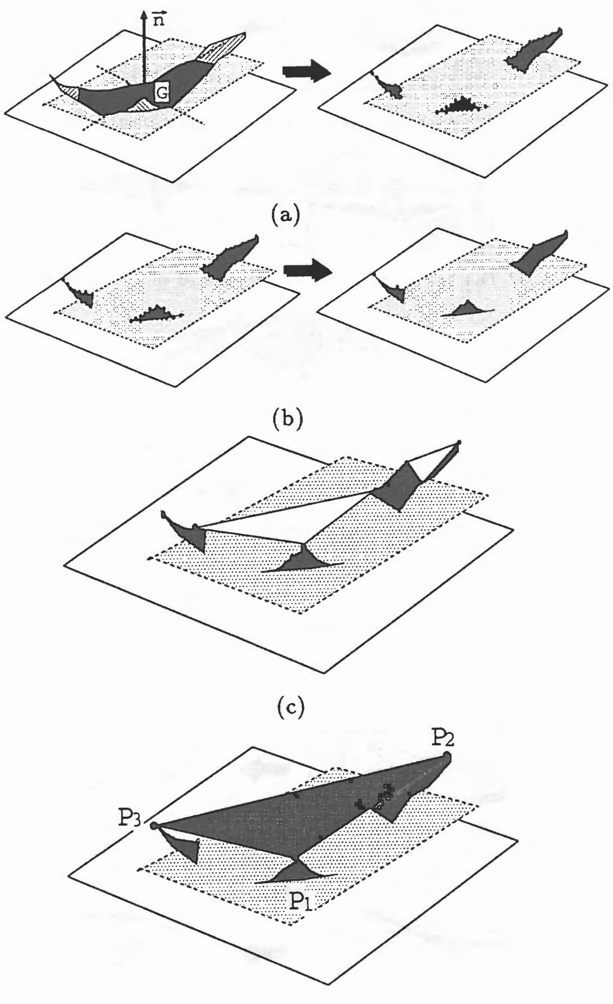


Fig. 4: Estimation of ground-contact point of back surface

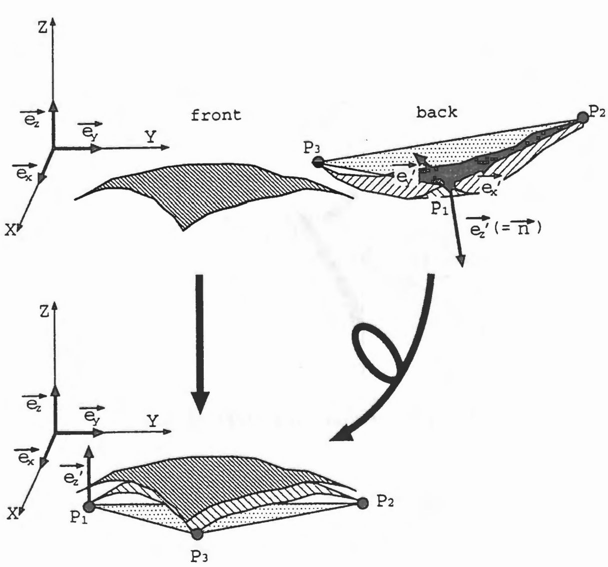


Fig. 5: Coordinate system ransformation

2.3 Estimation of Ground Surface

To determine the ground-contact plane of relic shard, we need pick up points to which touch the ground. The ground-contact plane is determined as follows.

Process 1

Average plane of a relic shard is calculated. The average plane is the plane that contains the gravity center G and has a norm vector n that is equal to the inertia axis c (fig. 3 and 4a left).

Process 2

All measured points on the back surface of the relic shard are set to candidates of ground-contact points. Then the distance d to the average plane is calculated for every candidate points. The points whose distance to the average plane is negative are omitted from candidate point set (fig. 4a).

Process 3

For every 5x5 region on the candidate point set, every point except one that has maximum of d is omitted (fig. 4b).

Process 4

All combinations of three points are created. The set of these three point combinations, or triangle set, is denoted X (fig. 4c). Here S denotes a subset of X that all measured points in the set S are on one side against X.

Process 5

A triangle that has maximum size in the set S is determined as the ground-contact plane (fig. 4d).

2.4 Adjustment of Front Face and Back Face

Here we denote the coordinate system of the front face as the global system Σ_G, and the coordinate system of the back face as the local system Σ_L (fig. 5).

Now we define the eigenvectors of the Σ_G as in Equation (1).

$$e_x = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}, \quad e_y = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \quad e_z = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \cdots \quad (1)$$

We define the eigenvectors of the Σ_L as (e'_x, e'_y, e'_z). Equation (2) is true if and only if e'_z is equal to n, the normal vector of the ground-contact plane, and e'_x is equal to the vector from P_1 to P_2.

$$e'_y = e'_z \times e'_x \quad \cdots \quad (2)$$

Now consider a three-dimensional rotation matrix T that represents the transformation from Σ_G to Σ_L.

$$T(e_x \quad e_y \quad e_z) = (e'_x \quad e'_y \quad e'_z) \Leftrightarrow T = (e'_x \quad e'_y \quad e'_z) \quad \cdots \quad (3)$$

The Z-axis direction of the back surface shape data agrees the Z-axis direction of the front surface data by using the transformation T^{-1}.

Another mathematical transformation is required to adjust the front and back surface model. Their gravity centers and inertia are still misplaced at this time. We perform an Affine transformation on the back surface model so that the back surface model positions correctly (fig. 6).

3. RECONSTRUCTION OF TEXTURE

Texture image of a relic shard is obtained by a 3CCD digital video camera. The texture image is then mapped onto the reconstructed polygon model.

3.1 Adjustment of Texture and 3D Shape

To map the texture image on to the reconstructed polygon model, position and direction adjustment of the texture image is required. For this adjustment, we transform the texture image by Affine transformation A, where A denotes a matrix.

An Affine transformation factor A is given as follows.

$$R_1, R_2, \ldots, R_n; \quad R_i \equiv \begin{pmatrix} R_{ix} \\ R_{iy} \end{pmatrix} \quad \cdots \quad (4)$$

$$T_1, T_2, \ldots, T_n; \quad T_i \equiv \begin{pmatrix} T_{ix} \\ T_{iy} \end{pmatrix} \quad \cdots \quad (5)$$

$$AR = T \Leftrightarrow A = TR^t (RR^t)^{-1}$$
$$R \equiv [R_1 \quad R_2 \quad \ldots \quad R_n], \quad T \equiv [T_1 \quad T_2 \quad \ldots \quad T_n] \quad \cdots \quad (6)$$

Here R and T denote positions of corresponding points on the range data and the texture data respectively.

3.2 Polygon Model and Texture Mapping

We converted a set of three-dimensional points to a triangle mesh in order to build a photo-realistic computer graphics of a relic shard. The triangle mesh is constructed by connecting points and their neighbor points each other. Constructed triangle mesh model is called polygon model.

Then the texture image is mapped onto the polygon model. Corresponds of each vertices of the polygon model and each pixels of the texture image are calculated for the texture mapping. Mip-mapping technology is also performed on this texture mapped polygon model.

4. EXPERIMENT

We first examined accuracy of above mentioned three-dimensional reconstruction method. We applied an acrylic resin piece to examine the accuracy of the thickness of reconstructed the acrylic resin piece. We calculated thickness of the several points of the virtual pieces, and then compared to the real thickness.

Next, we applied real broken relics and ceramics (as imitation relics). We examined the reality of reconstructed virtual relics.

We used Kubota Cubist laser range finder as a three-dimensional surface shape digitizer. Size of area Cubist measures is 250mm x 200mm, with resolution of 512 x 512.

We also used Sony's digital video camera to obtain texture images of relics.

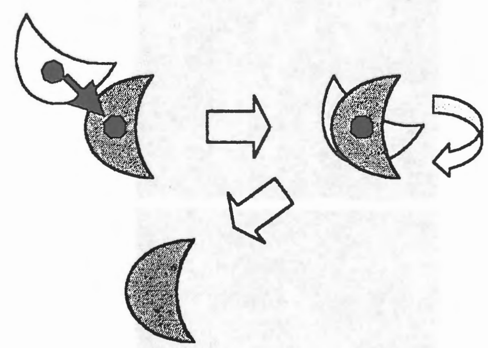


Fig. 6: Positioning of the front surface and the back surface.

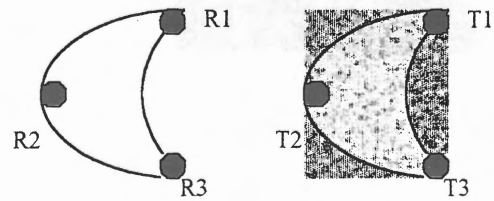


Fig. 7: Adjustment of positions between the depth image taken by a laser range finder (left) and the texture image taken by a video camera.

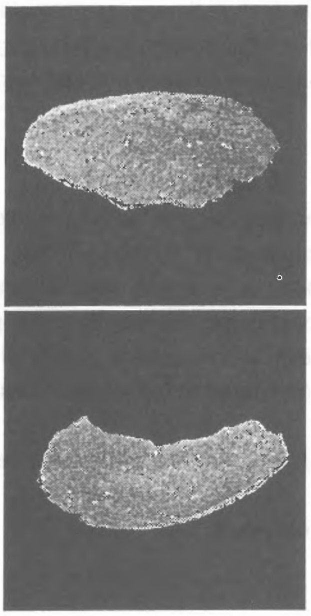


Fig. 8: Reconstructed 3D model of a relic shard (upper: front surface, lower: back surface).

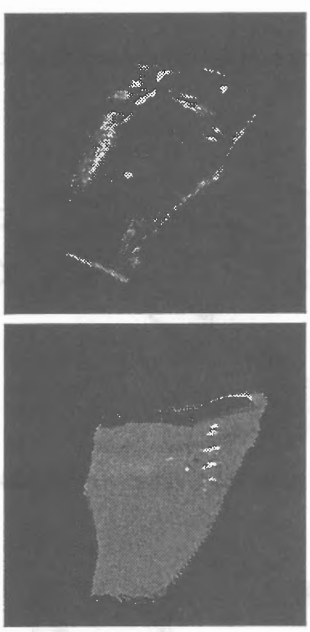


Fig. 9: Reconstructed 3D model of an imitation relic shard (upper: front surface, lower: back surface).

5. RESULT

We applied acrylic resin piece to our three-dimensional reconstruction method for testing the accuracy of our method.

Table 1 shows calculated thickness of three different points of the virtual piece. In Table 1, "Manual" raw shows the reconstructed thickness of three different points of the virtual relic whose ground-contact plane was specified manually. The following "Error" raw shows the difference between the real thickness and the reconstructed thickness.

The "Auto" raw of Table 1 shows the reconstructed thickness of the virtual piece whose ground-contact plane was determined automatically. The following "Error" raw shows the difference between the real thickness and the reconstructed thickness.

Table 1: Thickness (Unit: mm)

Point	Manual	Error	Auto	Error
1	3.83	0.83	3.52	0.52
2	3.83	0.83	3.26	0.26
3	3.73	0.73	3.54	0.54

We also build computer graphics of three-dimensional model of real relic shard and ceramic shard by above mentioned our approach. The results are shown in Fig. 8 and Fig. 9.

6. DISCUSSION

The experimental results show that we have achieved enough reality and accuracy on reconstructing three-dimensional model of relic shards. However, there must be some kinds of relic shards that our approach could hardly handle with. For example, our approach cannot find a ground-contact plane of shards whose silhouette on X-Y plane is symmetrical with regard to their gravity centers or inertia. We think our approach is still effective on archaeology use since symmetric relic shards are hardly fond from ruins.

7. CONCLUSION

We have achieved three-dimensional modeling of relic shards using laser range finders. Each shard is scanned twice: front face and back face. Then the front surface data and the back surface data are integrated under a constraint of physical modeling. We also mapped the texture of the shard onto reconstructed polygon model of the shard.

We applied our approach to real broken relic pieces, imitation relic shards made of ceramics and several acrylic resin pieces. The results show enough accuracy and reality for archaeology use.

By our approach, we are able to build three-dimensional model of almost all of shards excavated from ruins. We can expect that the digitized three-dimensional shard models are very useful for record, analysis and/or restoration of relics. Distribution of relic data via WWW would be possible.

REFERENCES

Kanaya, I., 1997. Restoration of Relics using Virtual Reality Technology (Japanese). Information Archaeology, 3 (1), pp. 35-46

Watanabe, Y., 1997. Relics Restoration by Using Virtual Reality Technologies (Japanese). Technical Report of IEICE, The Institute of Electronics, Information and Communication Engineers, PRMU-97-76, pp. 33-40

Foley, 1990. Computer Graphics Principles and Practice [Second Edition in C]. Addison-Wesley, pp. 471-532, pp. 741-744

Watt, 1992. Advanced Animation and Rendering Techniques. Addison-Wesley, pp. 65-201