# SURFACE MODEL GENERATION BY THE RELICS FROM SLICE IMAGES, AND THE TRIAL TO THE AUTOMATIC RESTORATION

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**ABSTRACT:**

The relics that unearthed from the monument break well. The restoration work is necessary to the research, the analysis and the exhibition. The restoration task uses relics directly, and it takes very terrible time at the expert. Moreover, we have the possibility to inflict damage on the relics because we glue together and restore fragments. Therefore, we generate 3-D shape models in the computer and the restoration task is done. The measurement doesn't use the laser measurement that excels in getting the small shape of the surface, and uses the X-ray CT that measures the thickness of the fragments. We state the method that generates surface models automatically using the X-ray CT, and the restoration task is done in the computer.

The restoration task in the computer never inflicts damage on the relics. However, because the restoration task is manual operation, the restoration time doesn't change. That we use as the restoration simulator that returns the value of the fragment is very inefficient. Then, the automatic restoration is desired. Because X-ray CT maintains the cross section shape information of the fragment that is difficult in the laser measurement, we aim at the automatic restoration using the information. We find out normal vectors in the cross section and show an automatic restoration result.

## 1. INTRODUCTION

A relic excavated from remains appears as a collection of smaller fragments. For the research of the culture or technique of the age when the relic was produced or the exhibition of the original shape, re-constructing task is necessary to have these fragments joined together. Such a restoration task is taken place using excavated fragments directly up to now. But this restoration task is very complicated generally, and there are many cases that the restoration succeeds as a result of thinking error. Further there is the problem that fragments can't be returned to the original states after the restoration because they are adhered together with glue. Consequently, a re-constructed relic will fairly receive breakdowns compared with the original one. Further we can't examine an individual fragment in excavation after the restoration task. On the other hand, the development of 3-D measurement technique makes it possible to measure correct 3-D shapes of fragments. Further, the development of computers makes it possible to display data of high capacity. So we can measure the shape of each fragment in excavation, and practice restoration without using genuine fragments because a computer successfully reproduce fragments using computer graphics.

So far a laser measurement device has been principally used for measuring each fragment, but it is difficult to get the backside and thickness of a fragment although the device can get the close shape and color information of each face. So an X-ray CT is began to use for measuring the internal shape of an object by acquiring a slice image (profile image) as shown in the Figure 1. Further because it has the transitivity, research on a relic or remains will have the broad possibility. Besides, for the restoration of a sophisticated model with a computer, a measurement with an X-ray CT is indispensable. Though a measurement with an X-ray CT can get a close internal shape, it becomes a problem that a connection between slice images becomes discontinuous. The image measured with the CT is modeled with voxels, but the data volume becomes so big that a strong machine power is necessary. So the surface model making the data volume comparatively small becomes necessary.

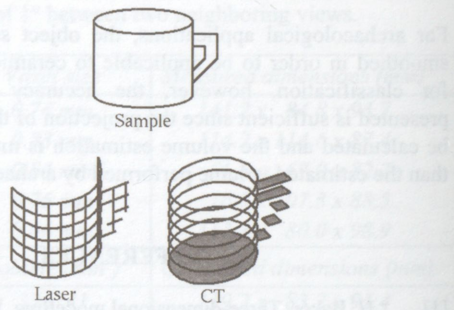


Figure 1. Difference in measurement methods

A surface model consists of a set of surfaces or boundary surfaces. Any surfaces of a 3-D object completely separate the outside from the inside of it, and must intersect with neither it nor any other surfaces. Besides, it is a very complicated problem to decide the surface including an arbitrary 3-D object

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from voxel data of the object with a computer instead of the data of surfaces.

Because various interpretation in determining a surface is possible, many different surface construction algorithms are proposed, but needs to intervene with a man' hand for complicated shapes. So the aim of this research is to generate automatically a complete surface model from slice images of very complicated shape measured with an X-ray CT.

So far all the restoration task is done by the manual operation at present. As long as we manipulate the relic fragment in virtual space, efficiency in this restoration task is not improved. Then, the automatic restoration is desired.

The precise shape information of a cross section of each fragment, which cannot be acquired with the laser measurement, can be easily got with our method using CT. Therefore, we aim at the automatic restoration using the information.

## 2. RELIC MEASUREMENT BY USING X-RAY CT

The laser measurement can measure only the shape of the irradiation range, the measurement doesn't suit to reproduce a cross section and the back of relics. In this research, we used X-ray CT to measure a complicated shape. X-ray CT is the measurement device that measures 3-D space by the slice image. Because CT measures 3-D space, we don't have to place fragments in a plane. A resolution of CT is not inferior compared with the laser measurement.

We fill fragments into the box (15cm × 15cm × 30cm) with the sponge that the CT value is different from the fragment. X-ray CT needs 20 seconds to measure 30 cm distance. And, the time, which produces a slice image from the CT exclusive use data, is 30 minutes. X-ray CT can measure the luster surface that it is difficult to measure by the laser measurement. However, the texture in the surface cannot be measured.

## 3. SURFACE MODEL GENERATION BY THE RELICS FROM SLICE IMAGES

The general model generation method using slice images is marching cube method. The method forms a triangular polygon based on the pattern of picture elements that are within eight neighborhoods of an element on the contour of an image. A surface model of the high quality can be generated with the method. There is, however, the danger that a different shape may be formed if several polygons are erroneously set up. If a shape includes intense changes between two levels of slice, wrong faces are patched there. As a result, the resultant shape is wrong because portions to be originally connected one another are torn to pieces.

For modeling of increasing relics, we must avoid manual operation. In this chapter, we state an automatic modeling. Not to be influenced by the size and the complexity of the slice image, we do process of grid unit. By introducing an intermediate point, we can do process of grid unit even if the gap between two slice images with intense change. We show the procedure in the followings.

### 3.1 Pre-processing

An X-ray CT image is processed before setting up faces. The image that is provided with an X-ray CT for each slice image is expressed with gray shaded picture elements of monochrome. Figure 2 is slice image taken with X-ray CT. This image sequence is slice images of 1-mm interval but is actually measured in 0.2-mm interval. Because gray shaded images cannot be expressed in polygons, they must be binaries. It is called threshold process. A threshold value is set at an intense place of alteration. And, we extract contours.

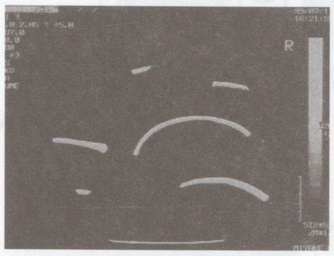

Figure 2. Slice image measured with X-ray CT

### 3.2 Approximation of a contour using a set of grid points

A salient characteristic of this research is a face tension with a grid unit. The finer a grid unit becomes, the more precise the approximation is. Points that a contour and the grid cross are selected to approximate the contour as shown in the Figure 3.

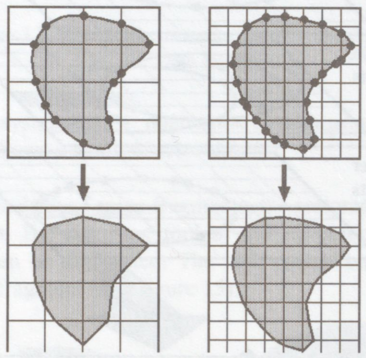

Figure 3. Approximation of a contour using a set of grid points

### 3.3 Intermediate points

A salient characteristic of this research is an intermediate point. An intermediate point is a point on the image obtained by taking difference of one slice image and another one. A detailed procedure is described using the Figure 4 as an example.

**AND information:** An AND collection is an intersection of two pieces of slice image. This portion is the region which polygon isn't set. Using this information, wrong selection of points nearby is avoidable even if the gap between two slice images with intense changes is interpolated.

**Intermediate information:** The difference information obtained by subtracting the AND information from the OR one mediates between a contour of lower slice from that of an upper one. In other words we don't need to look for corresponding points between adjacent contours. Intermediary points is obtained by taking grid points included this difference information. The intermediate points are completely separated from the list structure mentioned above.

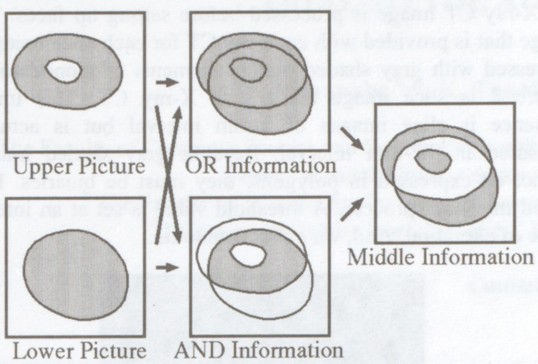


Figure 4. Procedure for generating intermediate points

### 3.4 Process of grid unit

Because making correspondence between contours is difficult, intermediate points are exploited in this research. Without the search of corresponding points between contour, faces filling a gap between adjacent slice images are successfully set as shown in the Figure 5 using intermediate points.

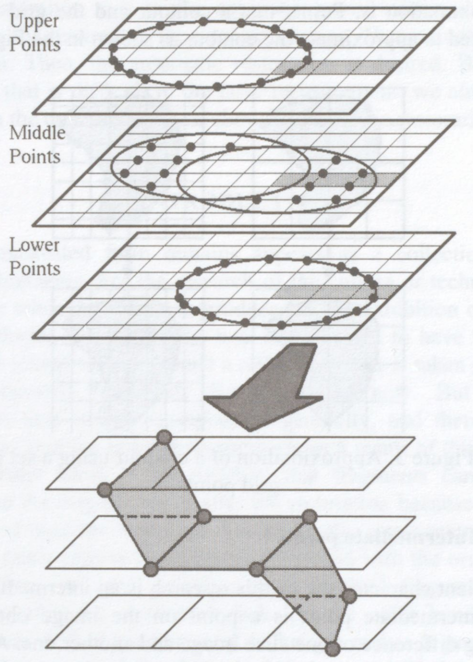


Figure 5. Face extension for each unit grid

### 3.5 Labeling

There is the face that should be distinguished as shown in the Figure 6 when faces are dealt with grid unit. In other words it is a remaining portion obtained by removing both ‘AND portion’ and ‘Exception of OR portion’. We don't set up face on this portion. We have only to perform face tension particularly.

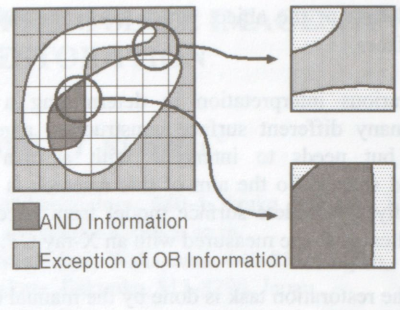


Figure 6. Areas in which face extension is

### 3.6 Face tension algorithm

The face tension is performed with respect to both grid unit and label unit. Tracing picture elements according to the direction of list structure, surfaces are set up as shown in the Figure 7. Because the direction of the face (normal) vector is the direction of the right screw as shown in the Figure 8, we define the list structure of the upper slice as the clockwise direction, and we define the list structure of the lower slice as the counter clockwise direction. This allows every surface to be set up smoothly. A twisted portion can be patched up without any problem. Further for a set of grids where only intermediate points exist, the direction of a face can be easily determined from relationship between the top and bottom image.

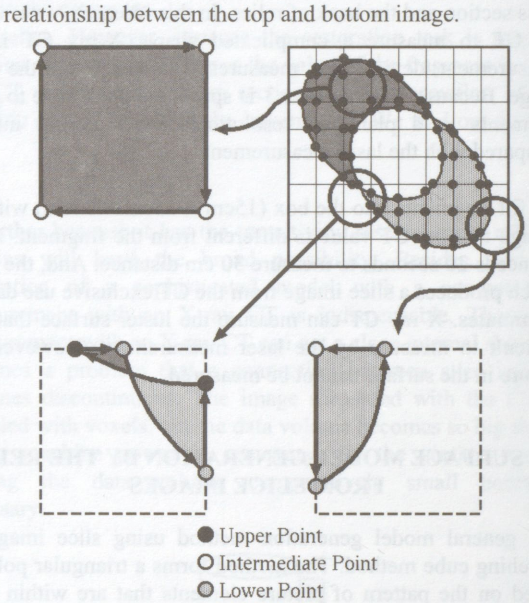


Figure 7. Face extension for a unit grid

### 3.7 Surface model generation

Pasting the surface of all grids, a surface model of an object is generated as shown in the Figure 9. Because the model becomes a stair stepping when the intermediate point is constant, we specify the height of the intermediate point using the ratio with distance to the upper and lower slice image. Repeating this process over the consecutive pair of contours, a surface model is completed.

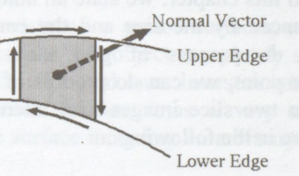


Figure 8. The direction of the normal vector

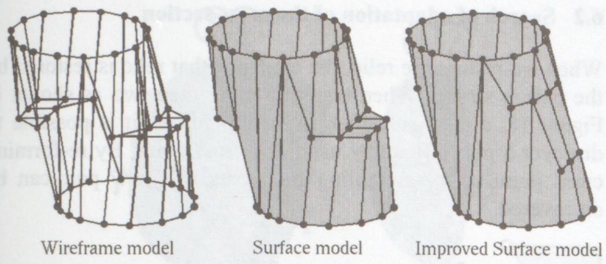


Figure 9. Face extension between two layers of slice images

## 4. RESTORATION SYSTEM USING VR

After generating a model at the relics, we work in the restoration. A restoration system configuration is shown in the Figure 10. We see virtual space at the stereo using HMD (Head Mounted Display). We hold object with the 2-D mouse and we work in the restoration with 3-D magnetic sensor.

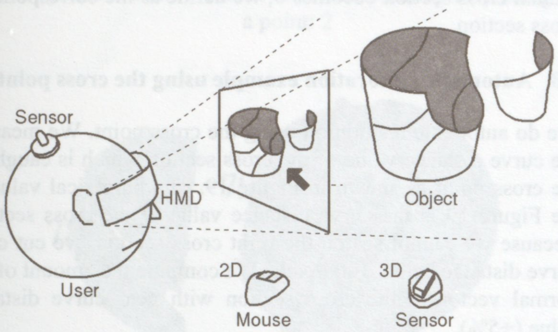


Figure 10. Restoration system using VR

## 5. RESTORATION RESULT

### 5.1 Relic model generation

The used relics are the KOIMARI bowl as shown in Figure 11. Surface models generated from the given relic fragments using this algorithm are shown in Figure 12. Because the surface of the KOIMARI bowl is a luster surface, it is difficult to get with a laser measurement. But we can confirm that detail of the model is reproduced with an X-ray CT (see Figure 13).

Figure 11. Original fragment of KOIMARI bowl

### 5.2 Restoration of relics

The original shape of a relic is restored using fragments restored with this algorithm. In the restoration task, the original

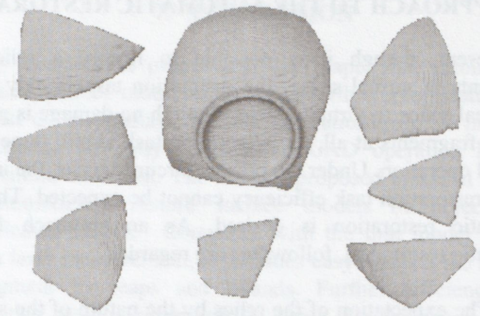

Figure 12. Surface model of KOIMARI bowl

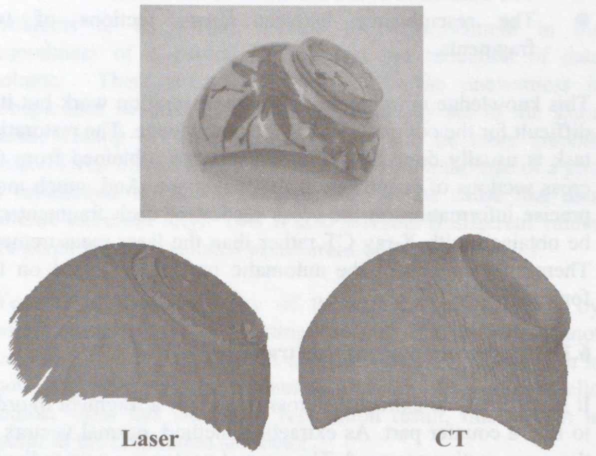


Figure 13. The generation comparison in the aspect of the luster

restoration system (see 4. restoration system using VR) is used. Figure 14 shows a result of restoration.

Owing to the lack of some fragments, the restored relics include broken part. By using the tool of the restoration system, the fragment can be duplicated. The lack part is buried using the duplicated fragment (see Figure 15).

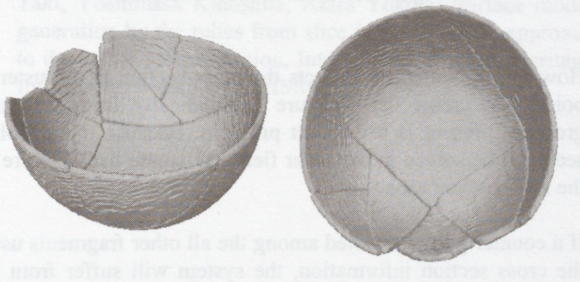

Figure 14. A relic restored with proposed method

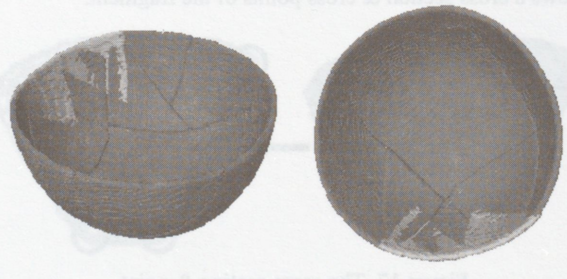

Figure 15. Virtual restoration

## 6. APPROACH TO THE AUTOMATIC RESTORATION

At present, though it is possible to restore a relic from fragments in virtual space, the restoration task is only moved from real space to virtual space. Though no damage is given to virtual fragments at all, the restoration task is still done by the manual operation. Under the present circumstances, the increase of the restoration task efficiency cannot be expected. Then, the automatic restoration is desired. As an approach for the automatic restoration, followings are regarded.

- The expectation of the relics by the nature of the soil and the find site.
- The utilization of the curvature of the model.
- The resemblance between cross sections of two fragments.

This knowledge is important with the restoration work but it is difficult for the computer to use this knowledge. The restoration task is usually done by exploiting, features obtained from the cross sections of fragments in the real space. And, much more precise information on the cross section of each fragment can be obtained with X-ray CT rather than the laser measurement. Therefore, we aim at the automatic restoration based on the former strategy.

### 6.1 Cross section & point extraction

It is necessary to extract the cross section of a fragment in order to find a counter part. As extracting method, normal vectors of the cross section are used. The normal vector is a perpendicular vector to the surface. In comparison with the normal vectors of the neighbors by extracting one with different angle, the cross section can be found as shown in Figure 16.

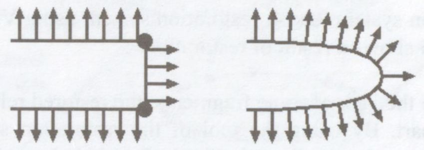


Figure 16. Cross section definition

However, this method extracts the cross section as a cluster of points. To create list structure automatically from the point group at present is a difficult problem. Because this problem seems to be solved in the other field, we create list structure by the manual operation.

If a counter part is selected among the all other fragments using the cross section information, the system will suffer from the inefficiency. Then, to aim only at the cross section information, we define a rapidly changing point as a cross point. Figure 17 shows a cross section & cross points of the fragment.

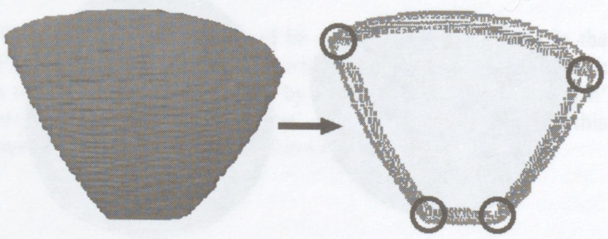

Figure 17. The cross section & point

### 6.2 Search of adaptation of the cross section

When we restore the relic, the tendency that relic is restored by the pair is strong. When restoring more than two as shown in Figure 18, a pair isn't often made. Therefore, it is possible to discover a pair efficiently using the cross point. By re-forming cross point after assembling fragments, the new pair can be discovered.

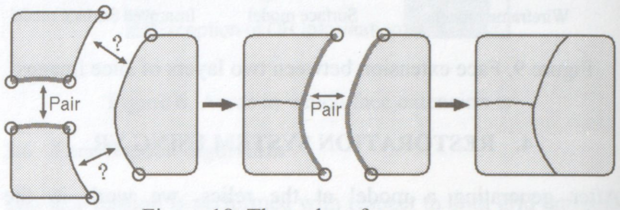


Figure 18. The order of a counter part

Using the normal vector, we search a corresponding cross section with pair. When the amount of the normal vector in the mutual cross section becomes 0, we define as the corresponding cross section.

### 6.3 Automatic restoration example using the cross point

We do automatic restoration using the cross point. We measure the curve distance value of the cross section which is caught in the cross point as shown in Figure 19. The numerical value of the Figure 19 is the curve distance value of the cross section. Because we cannot search the right cross section, we cut off a curve distance below 100 pixels. We compute the amount of the normal vector in the cross section with near curve distance value (±5%).

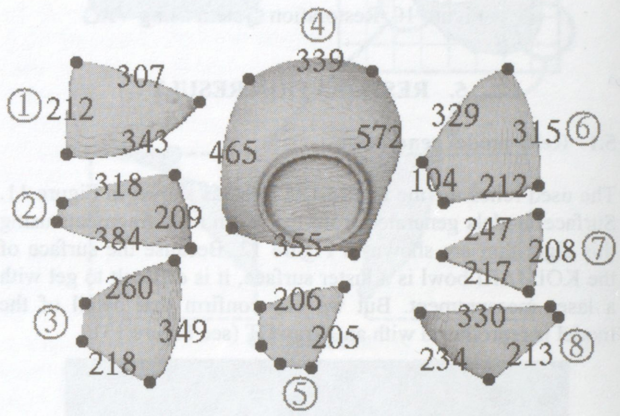


Figure 19. The automatic restoration example by using a point: 1

The search in the cross section with near curve distance value was 19 patterns. By worker's excluding fragments with different thickness, we chose 5 patterns as shown in Figure 20. Moreover, we got the result as shown in the Figure 21 by more searching. Then, we find that the [2,7] pair of the Figure 20 is a mistaken result. Because the computer can handle overlapping fragments, the trial and error is easy. In the last, we got a result as shown in Figure 22.

The error is born whenever continuing restoration, and cracks are built. However, by this automatic restoration result, we can imagine the whole shape of relic. By getting a relic number from this automatic restoration result, this system is useful as the restoration simulator.

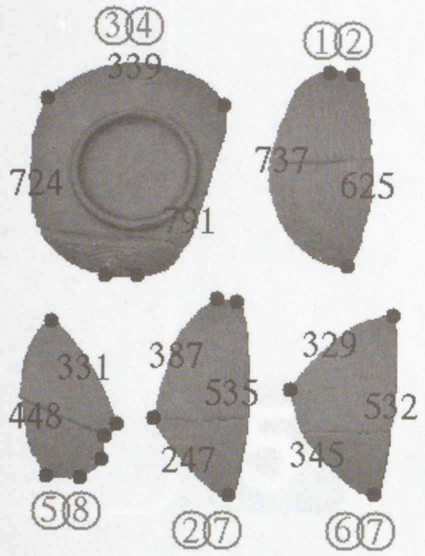


Figure 20. The automatic restoration example by using a point: 2

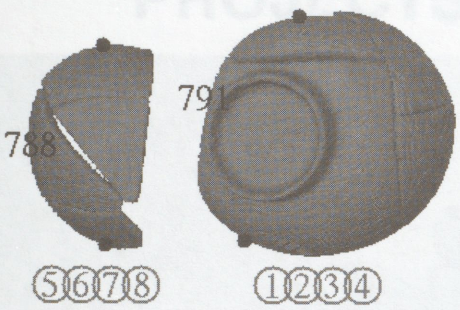


Figure 21. The automatic restoration example by using a point: 3

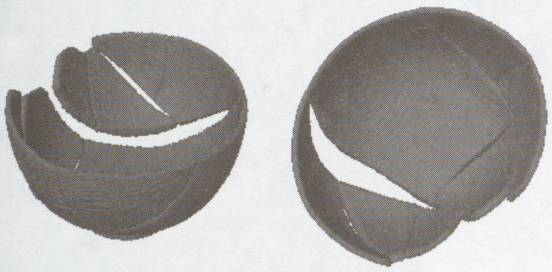

Figure 22. The automatic restoration example by using a point: 4

But, the system cannot search all corresponding cross section. In the case, we must restore by using the original restoration system. However, this system is more very efficient than the manual operation.

## 7. CONCLUSION

A new approach is proposed in this paper that automatically restores a surface model of an object with a complicated shape from the CT slice images. Model generation from CT images so far requires not only complicated CAD operation but also intervention of a man. The method proposed makes it possible to automatically restore surface models of objects with complicated shapes. Compared with the thin model restored with a laser measurement, it becomes easy to catch the shape of a fragment by leaps and bounds. Further efficiency of a restoration task is improved by using the thickness of each fragment.

Problems to be solved include the improvement in the smoothness of a curved surface and the reduction of data volume. There are often cases where the unevenness is conspicuous because all shading is currently set to the same value. Taking a proper normal vector can be more smooth model. Even for the portion of little inclination the size of a grid is established in the same value. This is the cause that data volume increases idly. This is also solvable if different values are given to grids included in the areas of intense changes.

We showed the possibility of the automatic restoration by extracting a section and setting a point. The system cannot search all corresponding cross section. However, this system is more very efficient than the manual operation. By getting a relic number from this automatic restoration result, this system is useful as the restoration simulator.

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