

Precise surface model generation from slice images for Medicine and Archeology

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Abstract

The research of a relic excavated from remains has become popular. In late years the research of a relic restoration using CG is also examined. But a laser measurement device is mainly used for measuring shapes of fragments and can't measure uneven complicated shapes. So the X-ray computed tomography to make 3-dimensional measurement possible has begun to be used as a measurement device, but the model generation needs the hand of man still more. In this research, we propose a procedure to automatically recover surface models of fragments with complicated shapes from slice images measured with an X-ray computed tomography. We have already reported a basic restoration system with MRI [1], and models restored with the system are useful to visualization or simulation of relic restoration. Regrettably, the models are not enough precise for experts such as archeologists to make detailed investigation possible. Much more precise models are needed to match the aim of experts.

To get a surface model, corresponding points of contours of two slice images must be found, but this is difficult without manual interposition of man. The surface model of a complicated shape is automatically formed by setting up a surface patch on each grid by interpolating intermediate points between the 2 corresponding contours. Further determination of the joining angle between two fragments became easy because re-construction of the thickness of each fragment is easily attained that is quite difficult to get using a laser measurement.

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-dimensional measurement technique makes it possible to measure correct 3-dimensional 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.

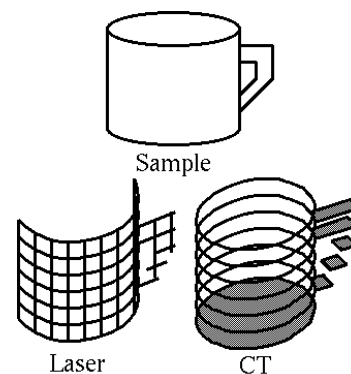


Figure 1. Difference in measurement methods

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 computed tomography scanner 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 computed tomography scanner is indispensable. Though a measurement with an X-ray computed tomography scanner can get a close internal shape, it becomes a problem that a connection between slice images becomes discontinuous. The image measured with the computed tomography 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.

A surface model consists of a set of surfaces or boundary surfaces. Any surfaces of a 3-dimensional 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-dimensional object 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 computed tomography

2. Model generation from slice images

2.1 As a traditional procedure

A voxel model is an aggregation of cells obtained by dividing 3-dimensional space into small unit cells. We can make a model easily by applying the unit cell to fill the interval between slices. Because voxel model just uses obtained CT values, a sophisticated model can be got. Further without forming any surfaces, a model can be provided whatever the shape is complicated. But on the other hand, a data volume increases so much that it becomes difficult to restore or display more than one fragment at a time. A method is called marching cube method that replaces with smooth surfaces the unevenness that is occurred with a set of unit cells when a surface model is generated from a voxel one. 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.

2.2 Procedure of this research

The sophisticated model closely resembling the real object is got by using a voxel model, but the data volume increases and visualization or restoration of more than one fragment becomes difficult. A help of man becomes necessary for complicated and non-continuous shapes that can't be handled by the above-mentioned procedure. A purpose of this research is to propose a method that makes it possible to cope with such complicated shapes. It is that salient merit of this research is to introduce intermediary points that make it unnecessary to find the correspondence between two

levels of slice image. We show the procedure in the followings.

3 Preprocessing

An X-ray CT image is processed before setting up faces. The image that is provided with an X-ray computed tomography scanner for each slice image is expressed with gray shaded picture elements of monochrome, each of which a value is calculated from attenuation at transmitting an object. Figure 2 is slice image taken with X-ray computed tomography scanner. This image sequence is slice images of 1-mm interval but is actually measured in 0.2-mm interval.

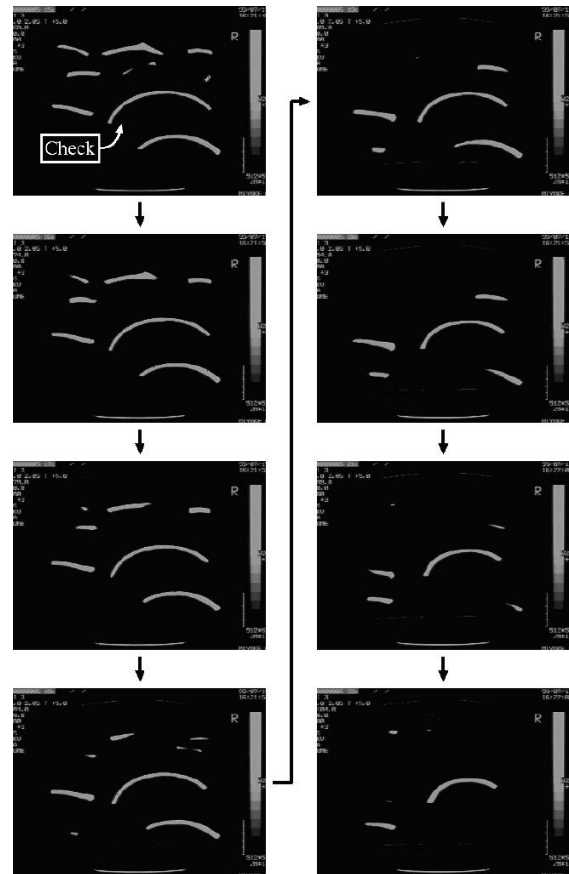


Figure 2. A sequence of cross sections of fragments measured with CT

Binary

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. Figure 3 is a binary image of the fragment checked in the Figure 2.

Interpolation of an image

Complicated images may include a thin portion consisting of a single picture element. Filling the portion with faces will result in a face without thickness. That is, it will cause a problem because no hollow surface model

is permitted. So, as a very easy but effective method an image of 3 times is generated. However, because we enlarge an image in length and breadth, the area becomes 9 times in substance. In addition, interpolation is performed. For every image, a hollow surface model can be generated for the portion consisting of a single picture element as shown in the Figure 4.

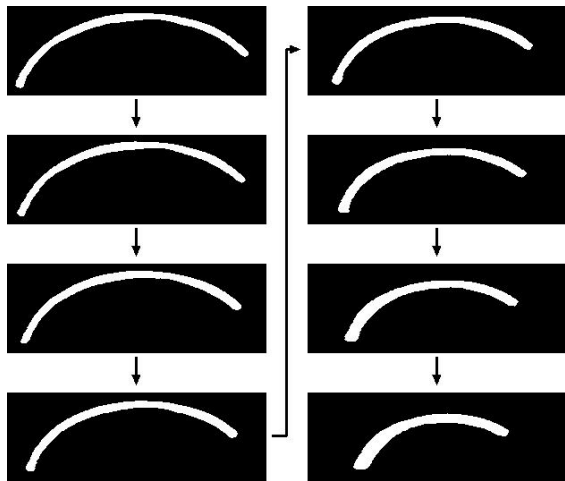


Figure 3. A sequence of cross sections of the fragment checked in the Figure 2

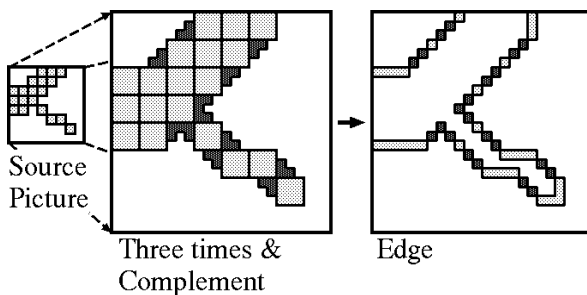


Figure 4. Enlarging and interpolating an image

Contour (an edge) extraction

Setting up a face needs to extract a contour. This is realized by using a brief patch.

3.1 Surface normal (a direction of a contour)

Each surface has a surface normal according to the contour enclosing the surface. So before extracting a contour, the direction of a face can be got by stepping on steps as shown in the Figure 5. This divides areas enclosed by consecutive two contours starting from the external frame of the image. In other words the first contour has an outward direction, and the next one in the opposite direction.

Contour tracing

Though details will be mentioned in the following chapter, a face is set up for every grid unit in the method, a list structure of contours becomes necessary. The list

structure can be got by tracing each contour referring to the direction of the face related to the contour.

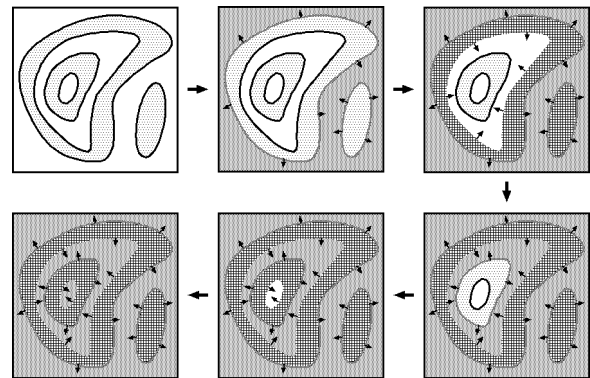


Figure 5. How to find the direction of each contour

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 6.

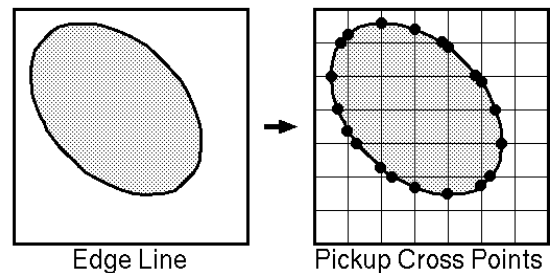


Figure 6. Extraction of a contour by using grid points

3.3 An intermediate point

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 7 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. And, the height of the intermediate points is not fixed. It is any decided by a distance of upper and lower slices.

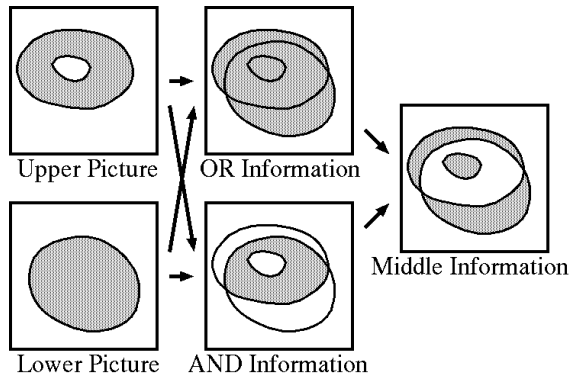


Figure 7. Procedure for generating intermediate points

4 Surface model generation

A surface model of an object is generated from the binary slice image as shown in the Figure 8. Connecting intermediate points and two levels of contour data provided with procedure shown previously, a set of surfaces connecting two levels of contour is generated. Repeating this process over the consecutive pair of contours, a surface model is completed.

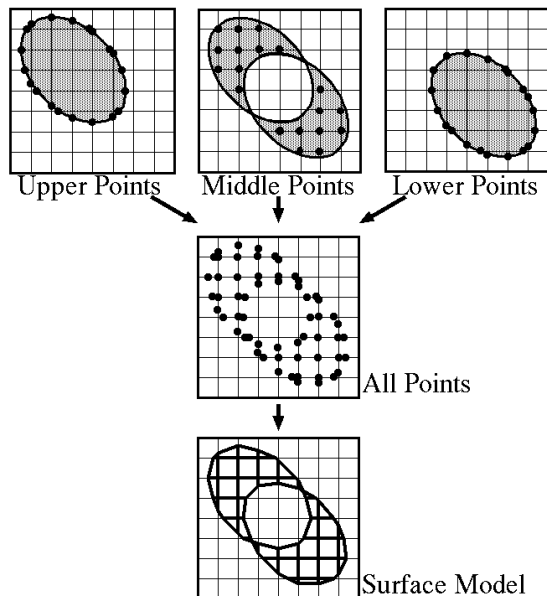


Figure 8. Flow graph of model generation

4.1 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 9 using intermediate points. The Figure 10 is finally obtained. Now, the intermediate points express the fixed height. But in fact, the height is decided by a distance of upper and lower slices.

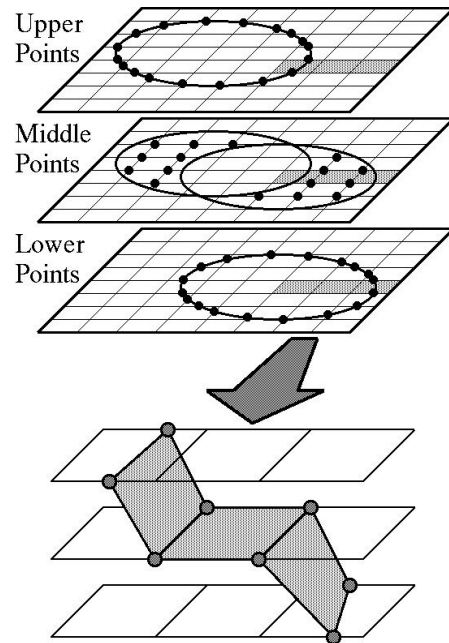


Figure 9. Face extension for each unit grid

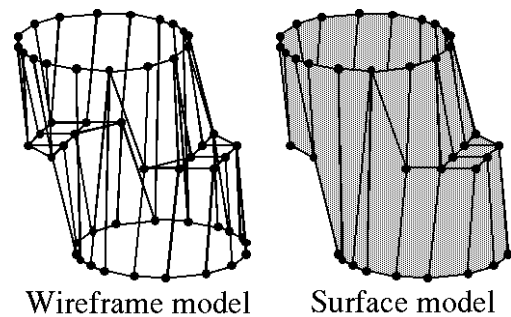


Figure 10. Face extension between two layers of slice image

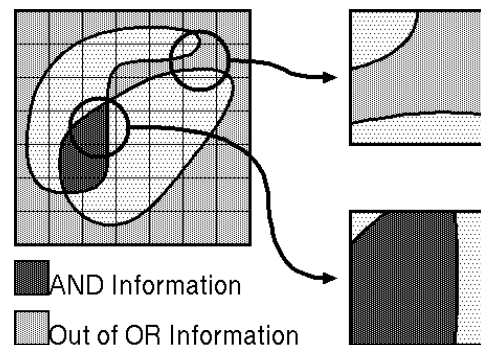


Figure 11. Areas in which face extension is inhibited

Labeling

There is the face that should be distinguished as shown in the Figure 11 when faces are dealt with grid unit. In other words it is a remaining portion obtained by removing both the AND portion and OR portion. We don't set up face on this portion. We have only to perform face tension particularly.

4.2 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 obtained in the previous chapter, surfaces are set up as shown in the Figure 12. Note here that picture elements must be traced according to the opposite direction of the list structure in the next slice image. This allows every surface to be set up smoothly. A twisted portion such as "e, f, g, h" in the Figure 12 can be patched up without any problem. Further for a set of grids "a, b, c, d" in the Figure 12 where only intermediate points exist, the direction of a face can be easily determined from relationship between the top and bottom image.

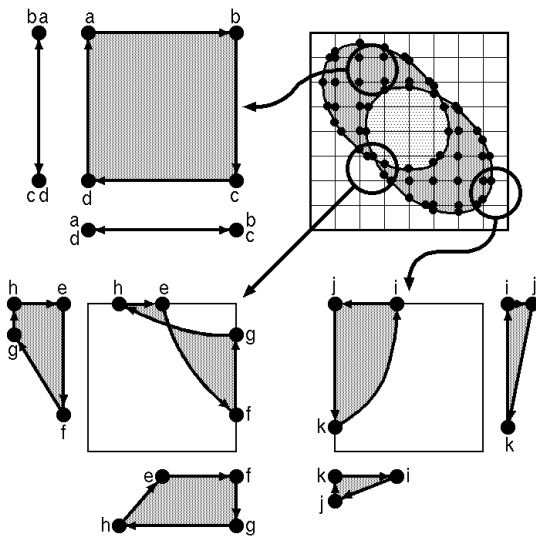


Figure 12. Face extension for a unit grid

5 Generation example of surface model

5.1 The restoring sample models

The restoring sphere

Surface models are generated from the given sphere using this algorithm. The sphere taken from the front and slant is shown in the Figure 13. The wire frame models in Figure 13 are shown in the Figure 14. It is characteristic of this algorithm that the wire frame model is grid.

The restoring holed pot

The model generated the holed pot in the Figure 15 is shown in the Figure 16. We can see that the inside and

the hole are clearly expressed. It is impossible to express this with a laser measurement.

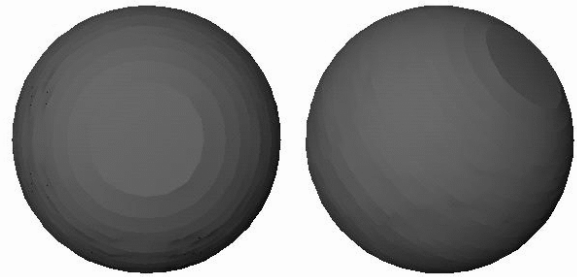


Figure 13. Model of sphere

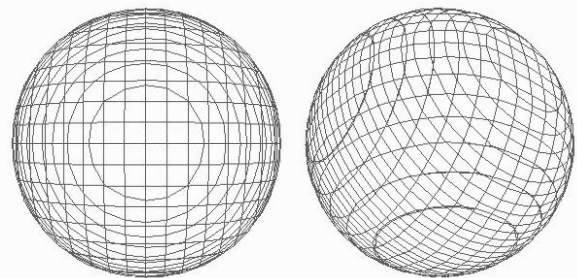


Figure 14. Wire frame model of sphere

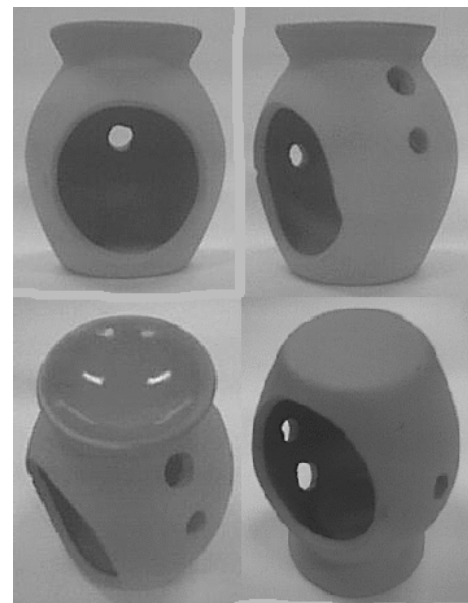


Figure 15. Original model of holed pot

5.2 The restoring relic fragments

Surface models generated from the given relic fragments (see Figure 17 and 18) using this algorithm are shown in Figure 19 and 20. We can see that the thickness of each fragment is clearly expressed, which is difficult to get with a laser measurement. And it is easy to catch characteristic of their shapes. The model magnified the turning point in the fragment in the Figure 19 is shown in the Figure 21. The wire frame models in Figure 21 are shown in the Figure 22.

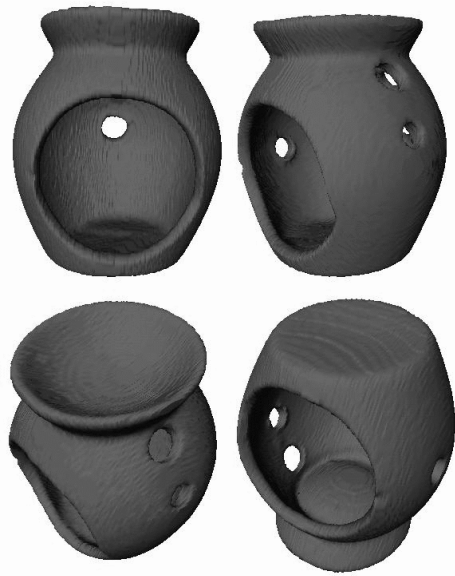


Figure 16. Model of holed pot

5.3 The restoration of relics

The original shape of a relic is restored using fragments restored with this algorithm. In the restoration task, the original tool we developed [1] is used. Figure 23 shows a result of restoration.

Owing to the lack of some fragments, the restored relics include holes. Generating models with CT prove that the one restored with the proposed method is easy to catch the characteristics of the original relic. The restoration task is extremely improved by referring to the thickness of fragments to be joined.

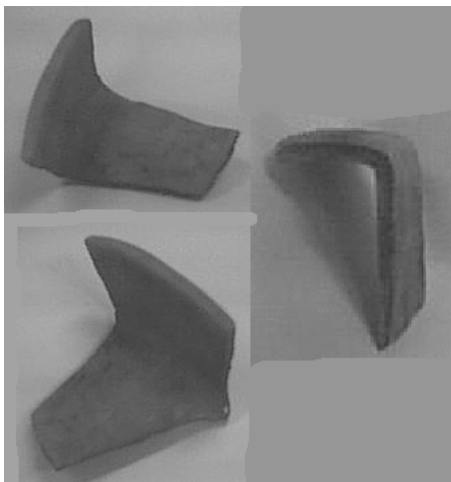


Figure 17. Original model of fragment



Figure 18. Original model of another fragment



Figure 19. Model of fragment

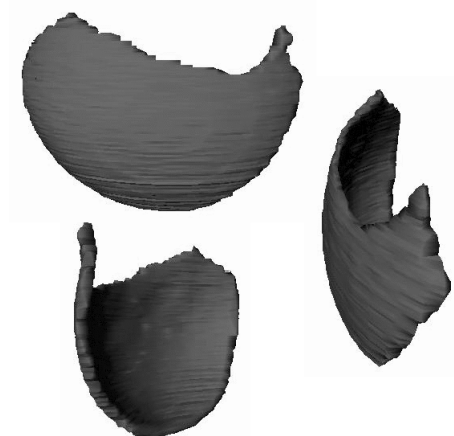


Figure 20. Model of another fragment

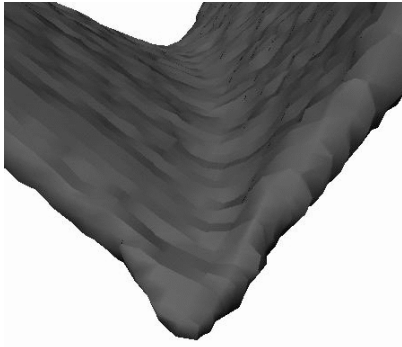


Figure 21. Model magnified the turning point in the Figure 19

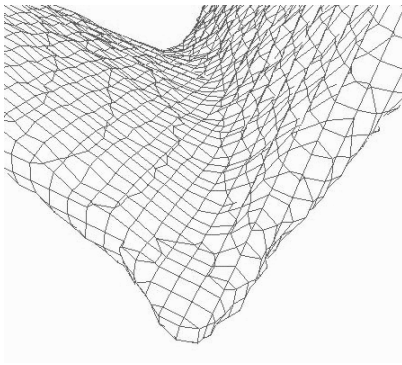


Figure 22. Wire frame model in Figure 21

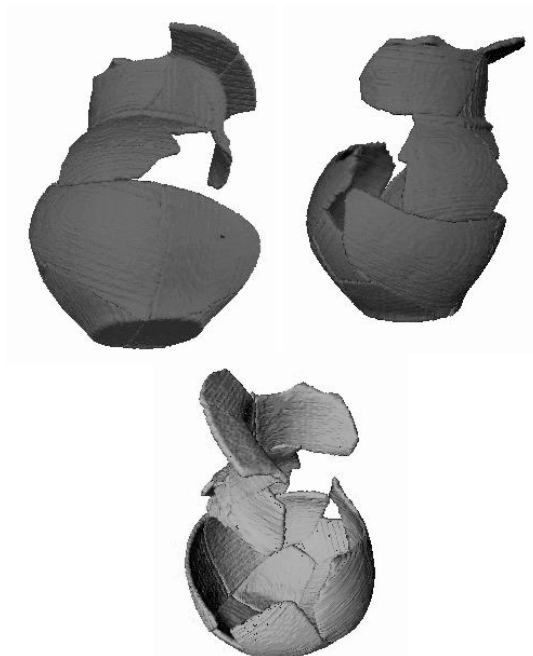


Figure 23. A relic restored with proposed method

6 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 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.

In regard to the future prospect, it is expected that the procedure proposed in this research can be applied to the medical images including very complicated shapes as shown in the Figure 24 as it can cope with a slice image consisting of complicated shapes with intense changes.

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 are 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 increase idly. This is also solvable if different values are given to grids included in the areas of intense changes.

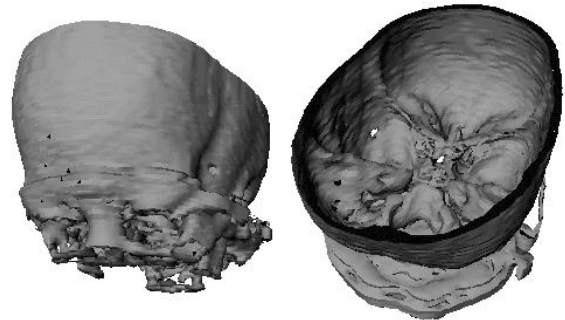


Figure 24. An example of restored skull

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