Surface model generation by the relics from slice images, and the approach to the automatic restoration

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ABSTRACT

The research of a relic excavated from remains has become popular. 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.

So far all the restoration task is done by the manual operation as long as we manipulate the relic fragment in virtual space. Then, the automatic restoration is desired. The precise shape information of a cross section of each fragment can be easily got with our method using CT. Therefore, we aim at the automatic restoration using the information.

KEYWORDS: CT, intermediate point, grid unit, normal vector, cross section & point, automatic restoration

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.

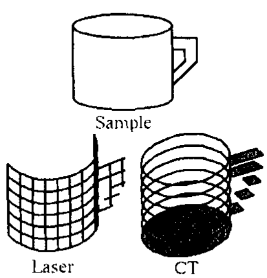

Figure 1: Difference in measurement methods

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

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 can not 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.

MODEL GENERATION FROM SLICE IMAGES

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 sooth 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.

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.

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.

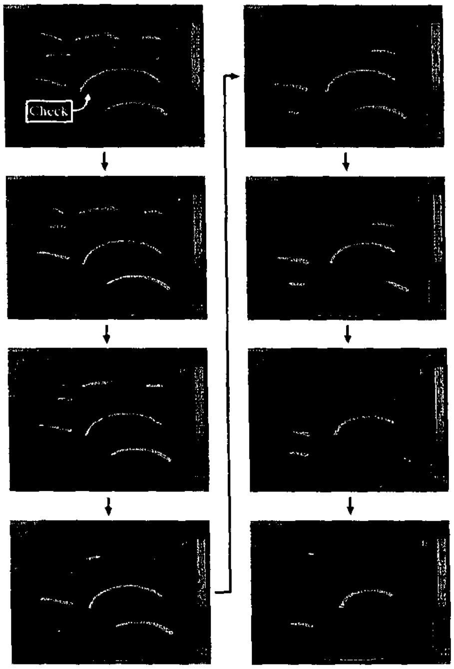

Figure 2: A sequence of cross sections of fragments masured with CT

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.

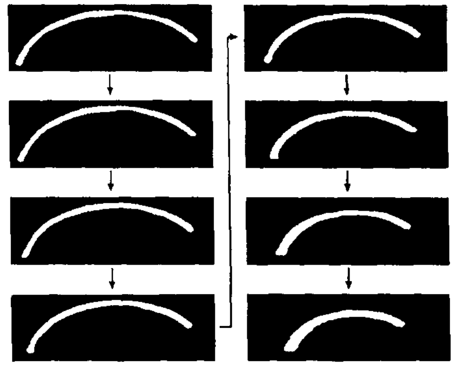

Figure 3: A sequence of cross sections of the fragment checked in the Figure 2

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.

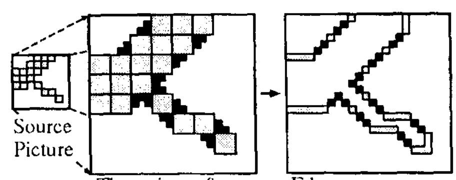

Figure 4: Enlarging and interpolating an image

Contour (an edge) extraction. Setting up a face needs to extract a contour. This is realized by using a brief patch.

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.

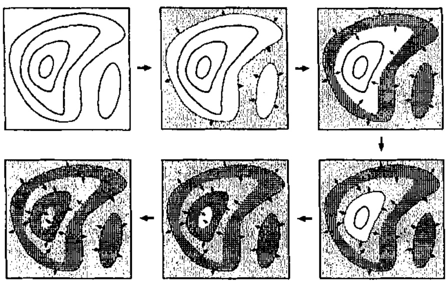

Figure 5: How to find the direction of each

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.

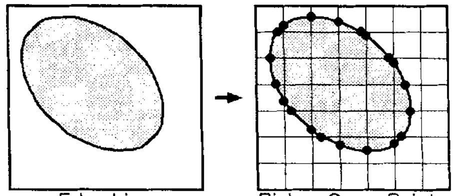

Figure 6: Extraction of a contour by using grid points

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 7 as an example.

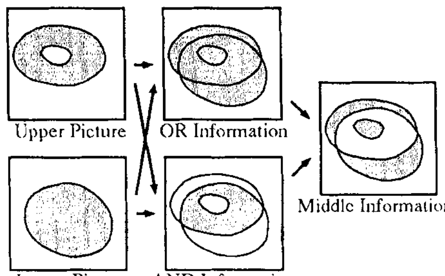

Figure 7: Procedure for generating intermediate points

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.

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.

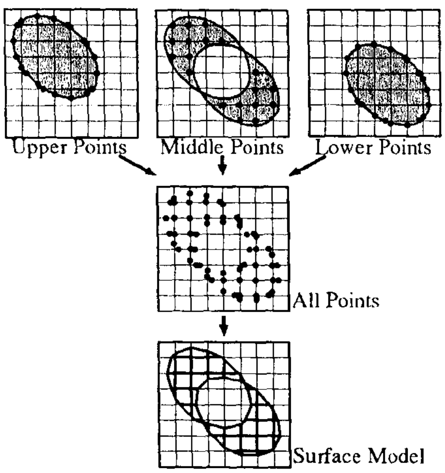

Figure 8: Flow graph of model generation

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.

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.

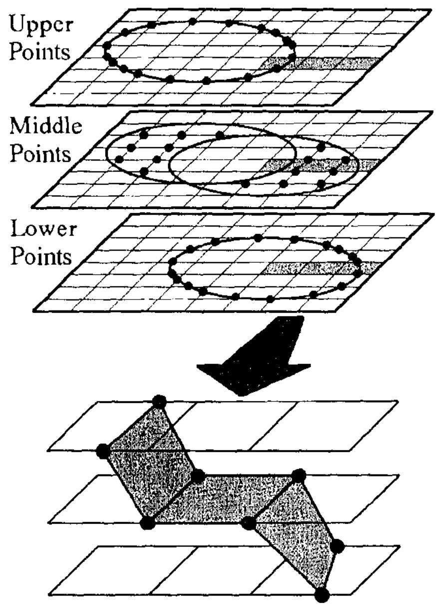

Figure 9: Face extension for each unit grid

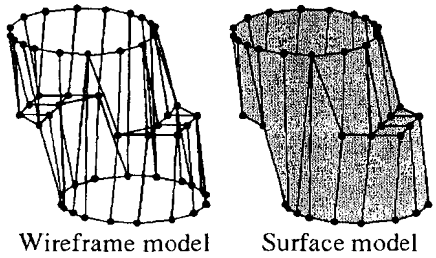

Figure 10: Face extension between two layers of slice image

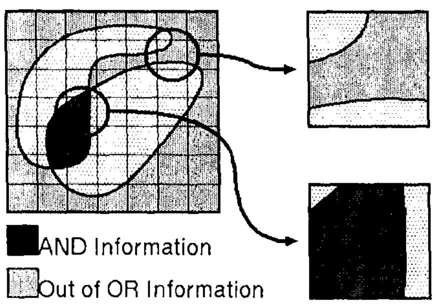

Figure 11: Areas in which face extension is

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.

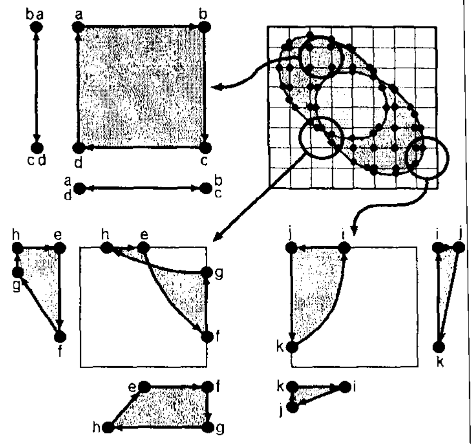

Figure 12: Face extension for a unit grid

GENERATION EXAMPLE OF SURFACE MODEL

Restoring sample models

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 shown in Figure 13 are shown in the Figure 14. It is characteristic of this algorithm that the wire frame model is grid.

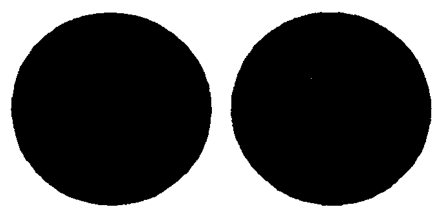

Figure 13: Model of sphere

Restoring holed pot. The generated model of the holed pot shown 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.

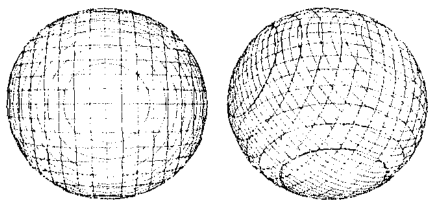

Figure 14: Wire frame model of sphere

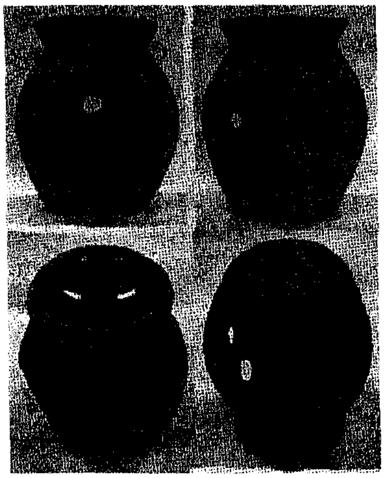

Figure 15: Original model of holed pot

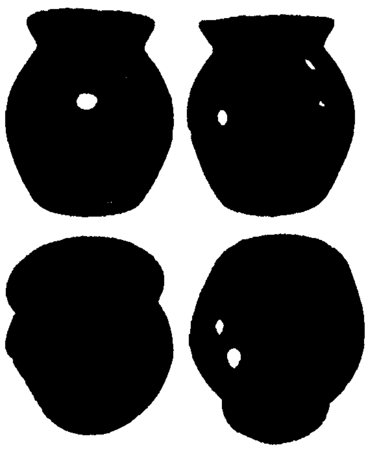

Figure 16: Model of holed pot

Figure 17: Original model of fragment

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.

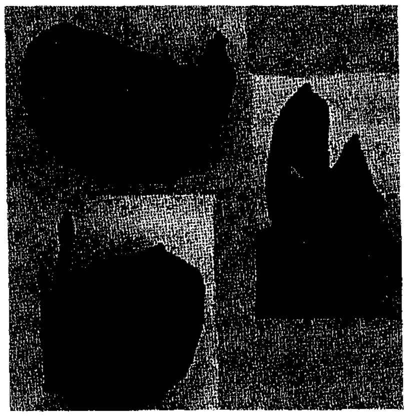

Figure 18: Original model of another fragment

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 19: Model of fragment

Figure 20: Model of another fragment

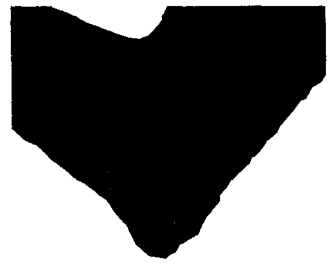

Figure 21: Model magnified the turning point in the Figure 19

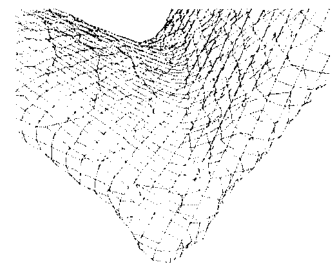

Figure 22: Wire frame model in Figure 21

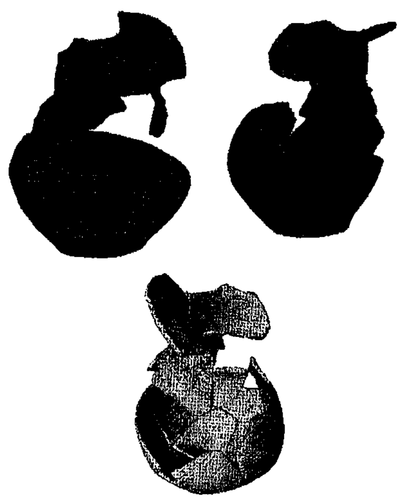

Figure 23: A relic restored with proposed method

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 can not be expected. Then, the automatic restoration is desired. As an approach for the automatic restoration, followings are regarded.

- The resemblance between cross sections of two fragments.
- The utilization of the curvature of the model.

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 CT rather than the laser measurement. Therefore, we aim at the automatic restoration based on the former strategy.

Normal vector

To begin with, the normal vectors must be calculated. To calculate a 3-D normal vector, the slice images with respect to X-Y-Z coordinates that are acquired with CT is insufficient. The imaginary slice images with respect to Y-Z-X and Z-X-Y which are calculated from the original ones are necessary as shown in Figure 24. The normal vector was obtained by integrating these 3 projected normal vectors as shown in Figure 25.

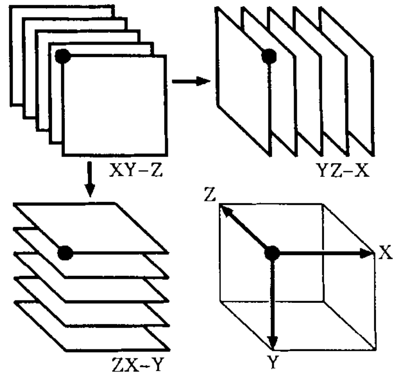

Figure 24: The virtual slice image

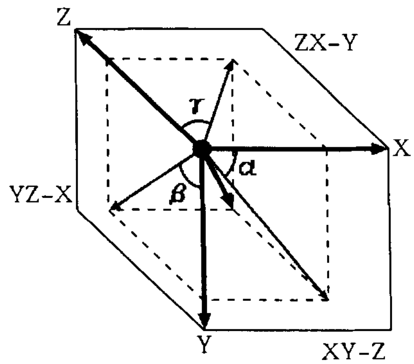

Figure 25: Normal line vector from three vectors

Cross section 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. In comparison with the normal vectors of the neighbors by extracting one with different angle, the cross section can be found. However, this method extracts the cross section as a cluster of points.

For the fragment shown in Figure 17 and the holed pot shown in Figure 15, the cross sections were extracted. Figure 26 shows a cross section of the fragment shown in the Figure 17. Figure 27 shows a cross section of the holed pot shown in the Figure 15.

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 as shown in Figure 28. 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 29, 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.

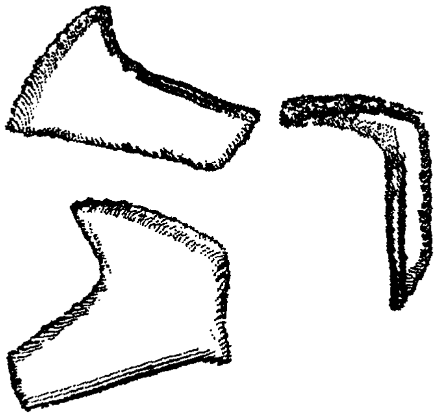

Figure 26: A fracture surface of Figure 17

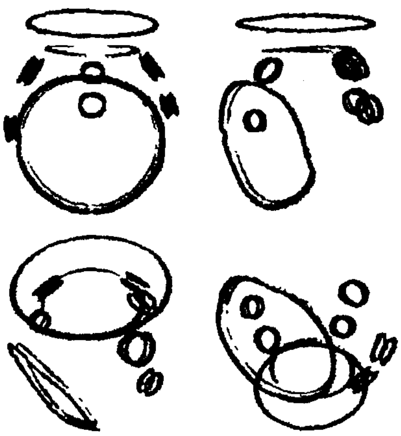

Figure 27: A fracture surface of Figure 15

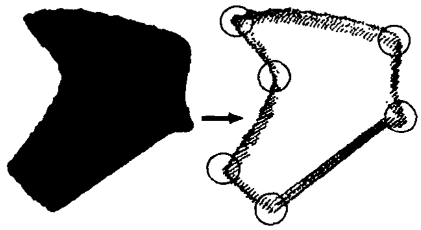

Figure 28: The cross point

Classification of fragments

If a candidate fragment which best matches to the given fragment is selected among the remaining all other fragments, it will take enormous time to find a right one, and to make matters worse, the case that erroneous one is selected will increase. However, the processing time can be also shortened, if fragments can be classified, and the more accurate matching can be done. For example, features of neck, base and side part of a pot are different each other. And, restoration starts from the fragments of which area are large even in the real space.

First, normal vector on the fragment surface is examined. If the normal vector with a constant direction can be found, it means that the fragment surface is flat and it will belong to the base of a pot. For example, the possibility that it is a part of a base of a pot is high. By examining only cross section information, the cross section with constant curvature can be found. This shows that it include a circular portion. For example, the possibility that it is a part of a neck or a base of a pot is high. And, if a bent pattern as shown on Figure 30 is observed when the cross section is seen from the direction of the axis of normal vector, this shows that it is a bent fragment. Classifying fragments satisfying the above mentioned characteristics will make it possible and easy to find a counter part to the given fragment and the risk of incorrect matching can be reduced.

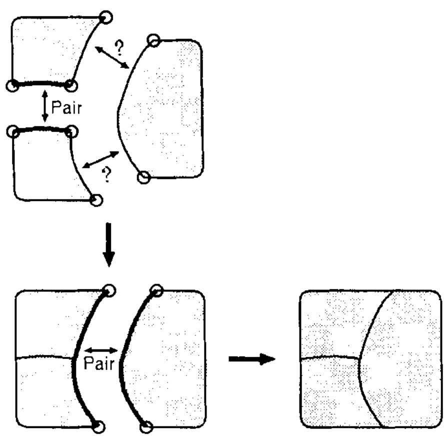

Figure 29: The order of a counter part

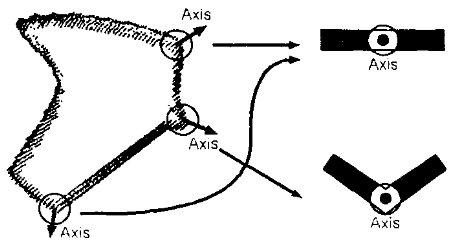

Figure 30: Classification of a bent fragment

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.

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 31 as it can cope with a slice image consisting of complicated shapes with intense changes.

Figure 31: An example of restored skull

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.

The approach to the automatic restoration is shown in the paper by classifying a fragment and extracting the cross section of the fragment. The future problem is to find a counter part for a give fragment. However, examining a normal vector on the fragment surface using the cross point,•it seems that it is easy to find a counter part.•That is, the section where the summation of all vectors on the cross section of a pair is near 0 should become a counter part. Calculating the curvature of a fragment surface and specifying the location and orientation of the fragment will help as realize the automatic restoration system.

REFERENCES

1. Yasuhiro Watanabe, Kazuaki Tanaka, Norihiro Abe, Hirokazu Taki, Yoshimasa Kinoshita, Akira Yokota: Measurement of Fragments with MRI and Relic Restoration Using Virtual Reality Technologies, the Transactions of the Institute of Electronics, Information and Communications Enginners of Japan (D-II), 31, 4, pp. 52-62, 2000.

2. Yasuhiro Watanabe, Kazuaki Tanaka, Norihiro Abe, Hirokazu Taki, Yoshimasa Kinoshita, Akira Yokota: Proposal of new method for generating surface model from slice images, International Conference on Virtual Systems and MultiMedia (VSMM), pp. 190-199, 2000.

3. W.E.Lorensen, H.E.Cline: Marching Cubes: a high resolution 3D surface construction algorithm, Computer Graphics (ACM SIGGRAPH '87 conference proceedings), 21, 4, pp. 163-169, 1987.

4. Kaneyama K, Chin K, Chihara K: Restoration of fragments using VR technology, Nara Institute of Advanced Science and Technology Research Report, pp. 9-14, 1996.

5. Norihiro Abe, Yasuhiro Watanabe, Kazuaki Tanaka, J.Y.Zheng, Shoujie He, Hirokazu Taki, Yoshimasa Kinoshita, Akira Yokota: Relics Restoration by Using Virtual Reality Technologies, International Conference on Computational Intelligence and Multimedia Applications, pp. 673-378, 1997.

6. Norihiro Abe, Yasuhiro Watanabe, Kazuaki Tanaka, J.Y.Zheng, Shoujie He, Hirokazu Taki, Yoshimasa Kinoshita, Akira Yokota: Virtual Reality Based System for Relics Restoration, International Conference on Virtual Reality and Tele-Existence (ICAT), pp. 122-128, 1997.

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