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TOWARD THE AUTOMATIC RESTORATION OF RELICSFROM SLICE IMAGE

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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 CT (Computed Tomography) to make 3-D measurement possible has begun to be used as a measurement device, but the model generation needs the hand of man still more. We have already reported a basic restoration system with MRI (Watanabe, 2000) and a procedure to automatically recover surface models of fragments with complicated shapes from slice images measured with X-ray CT (Watanabe, 2001), and models restored with the system are useful to visualization or simulation of relic restoration.

Though relics are never damaged by the restoration task in VR, so far the restoration task is done by the manual operation as long as we manipulate the relic fragment in virtual space. It is too inefficient to use it as the restoration simulator, because efficiency improvement of restoration task can't be expected. Then, the automatic restoration is desired strongly. 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.

Because the surface model has only surface information, we define cross section using normal vectors in the fragment surface, and extract cross section. As the extracted cross section is not a line but an aggregate of points, a list structure of a line enclosing the cross section must be extracted using a thinning operation. A pair of cross sections is tested if their list structures are matched each other, and a pair of cross sections is matched when the summation of the normal vectors in one cross section is approximately equal to another one. However, it is very difficult to search out all cross sections. By defining a rapidly changing portion of a cross section as a cross point, we can search a corresponding cross section easily. The precision of automatic restoration is below that of manual one.

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

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 reproduces 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 begun 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 X-ray 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.

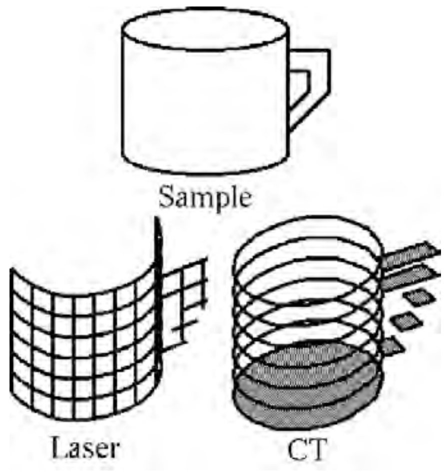


Fig1. Difference in measurement methods

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

Because various interpretations in determining a surface are possible, many different surface construction algorithms are proposed, but needs to intervene with a man's 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 the restoration task is entirely 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.

2. MODEL GENERATION FROM SLICE IMAGES

We measure relics using X-ray CT that can get a close internal shape and the cross section. Because the X-ray CT measures 3-D space, it can measure more than one fragment at once. So, we pack fragments using the sponge with different CT permeability as shown in Figure 2, and we measure slice images of fragments at 0.5-mm intervals.

Fig,2: Measurement fragments using X-ray CT

Procedure of this research: To make a surface model with the slice image, so far a method called "marching cubes method" has been used. The method 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.
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 CT 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 3 is slice image taken with X-ray CT. 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.

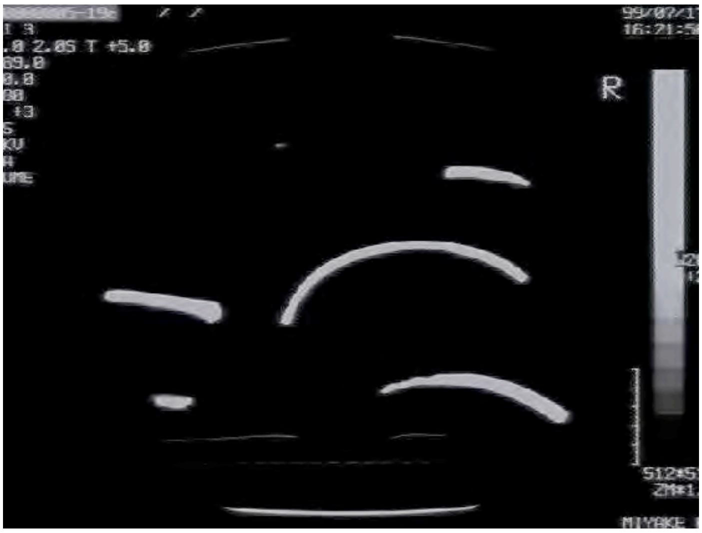


Fig.3 Slice image of fragments measured with X-ray CT

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.

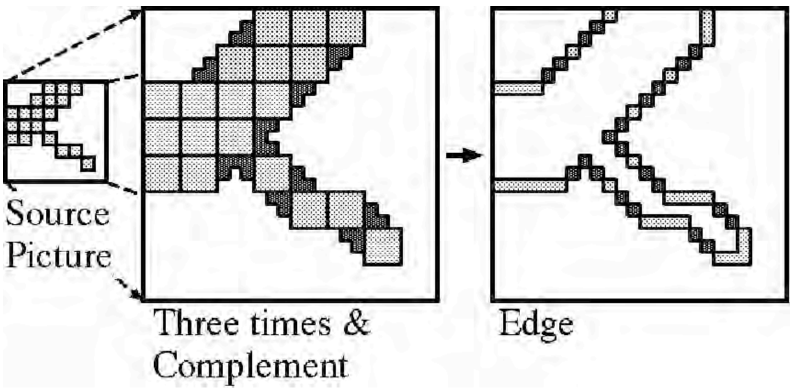


Fig.4 Enlarging and interpolating an image

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

Process of grid unit: 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 5.

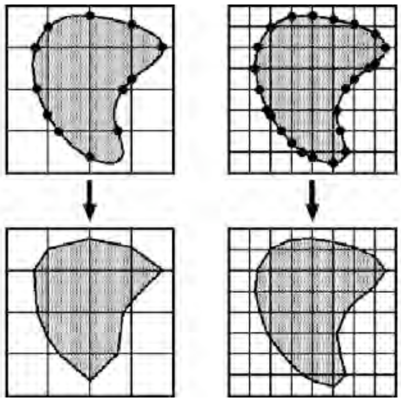


Fig.5 Approximation of a contour using a set of grid points

Intermediate points: 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 6 using intermediate points. 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.

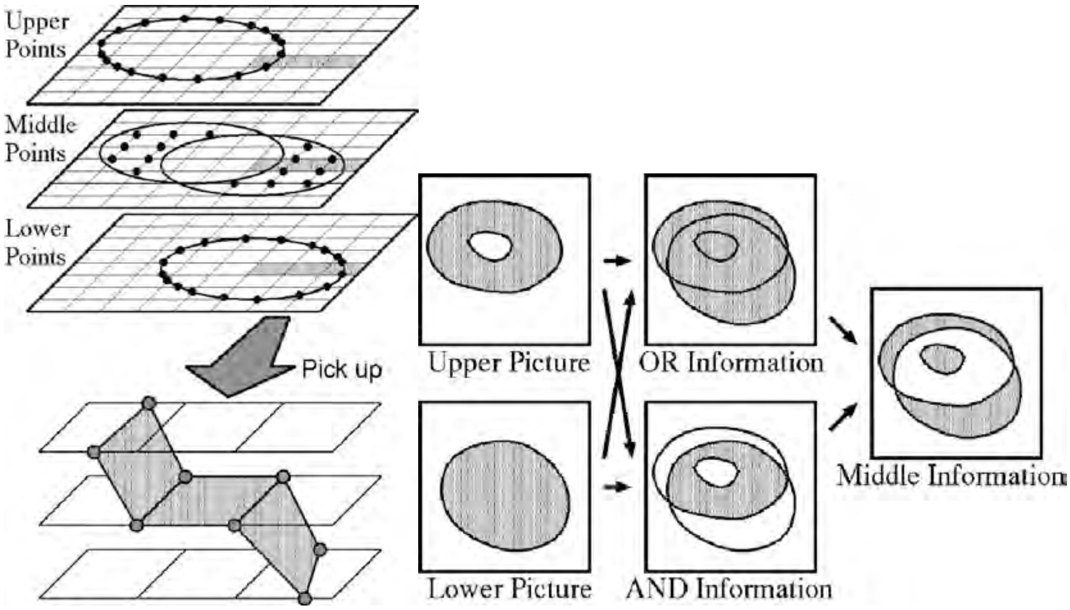


Fig6: Face extension for each unit grid / Fig7 Procedure for generating intermediate points

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.

List structure of the edge: Though details will be mentioned in the following chapter, a surface is set up for every grid unit in the method. So, a list structure of contours becomes necessary. Because the direction of the polygon surface is equal to the direction of the normal vector, a polygon surface is defined as the clockwise direction as shown in Figure 8. When we set the relation of any two layers as the upper and lower edges, the upper edge is clockwise rotation. And, the lower edge is counterclockwise rotation. To set up a right polygon surface, the list structure must be got by tracing each contour taken along the direction of the edge.

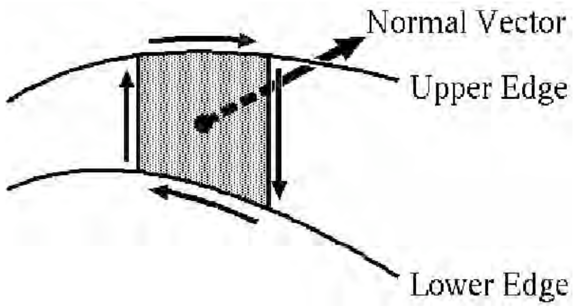


Fig.8 Direction on the polygon surface

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 9. 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 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. Connecting intermediate points and two levels of contour data, a set of surfaces connecting two levels of contour is generated as shown in Figure 10. Repeating this process over the consecutive pair of contours, a surface model is completed.

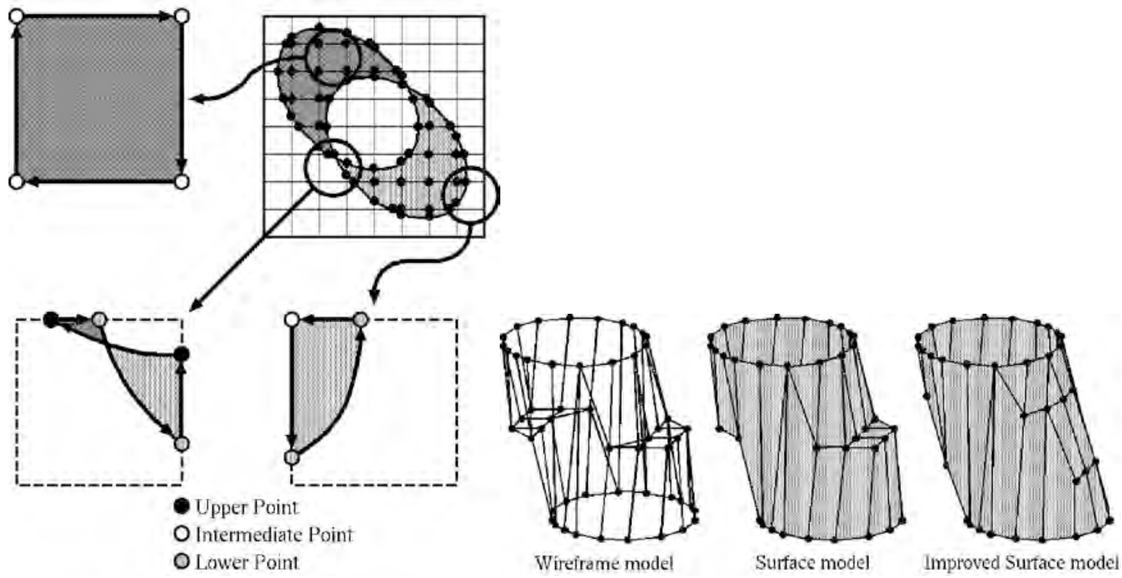


Fig.9 Face extension for a unit grid / Fig10 Face extension between two layers of slice image

Restoring IMARI-fragment: Surface models generated from the given a IMARI-fragment (see Figure 11) using this algorithm are shown in Figure 12. 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.

Fig11: Original model of IMARI-fragment / Fig12: Surface model of IMARI-fragment

Restoration of IMARI-relic: The original shape of a IMARI-relic is restored using fragments restored with this algorithm. In the restoration task, the original tool we developed (Watanabe, 2000) is used. Figure 13 shows a result of restoration. The restoration task is extremely improved by referring to the thickness of fragments to be joined.

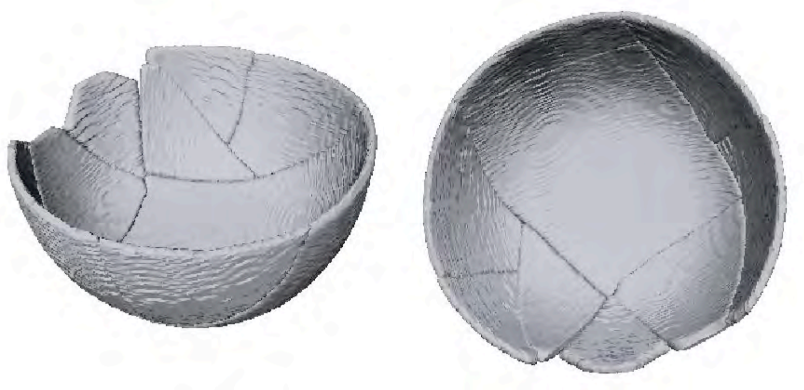


Fig.13: IMARI-relic restored by manual operation

3. TOWARD THE AUTOMATIC RESTORATION OF RELIC

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 expectation of the soil property and find spot of fragments

The utilization of the curvature of the model

The resemblance between cross sections of two fragments

The restoration task is usually done by exploiting, features obtained from the cross sections of fragments in the real space. However, it is difficult for the computer to cogitate these in formations. 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.

Cross section definition: It is necessary to extract the cross section of a fragment in order to find a counter part. However, the slice image measured by using CT doesn't recognize a cross section. So, the computer doesn’t recognize a cross section, too. We must teach a cross section to the computer. Because the cross section is a broken section of relic, many cross sections are not smooth. The cross section is the section which changes rapidly on the fragment surface. 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 as shown in Figure 14, the cross section can be found. However, this method extracts the cross section as a cluster of points. If there is space into the broad cross section, we must close a gap.

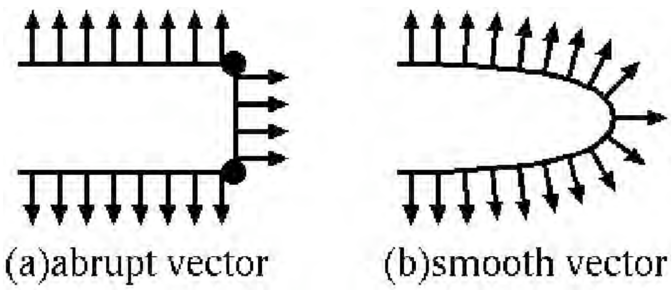
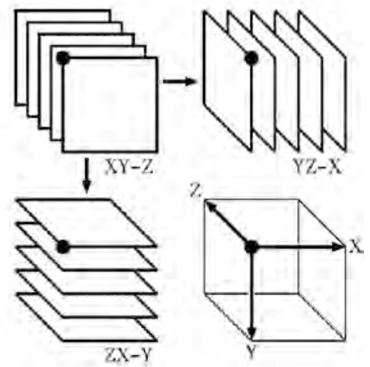


Fig.14 Cross section definition

Normal vector: To begin with, the normal vectors must be calculated for the cross section extraction. 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 15. The normal vector was obtained by integrating these 3 projected normal vectors as shown in Figure 16.



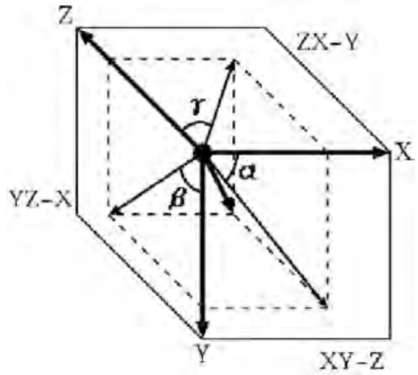


Fig15 The virtual slice image / Fig16: Normal line vector from 3 vectors

Example of cross section extraction: For the fragment shown in Figure 11, the cross sections were extracted. Figure 17 shows a cross section of the fragment shown in the Figure 11.

List structure of the cross section: Because a cross section is expressed by the aggregation of strip-shaped points, we must create list structure to impress a cross section on the computer as shown in Figure 18. So, we must do thinning operation (cf. next chapter). If we describe cross section as closed-loop, the computer extracts two closed curves of periphery and inside one. If the computer extracts a portion except the cross section, the cross section with thinning operation branches off. So, the computer extracts many more closed curves. By chasing these closed curves, we impress the specific list structure of a cross section of the fragment on the computer. Because the computer creates each list structure of each cross section, the computer can find a counter part without thinking of the branch of the cross section.

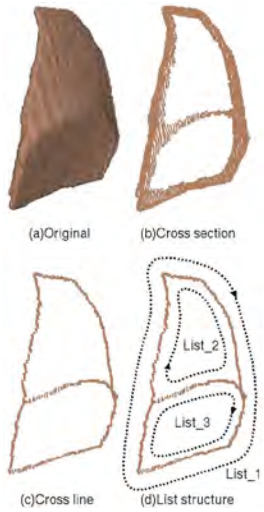
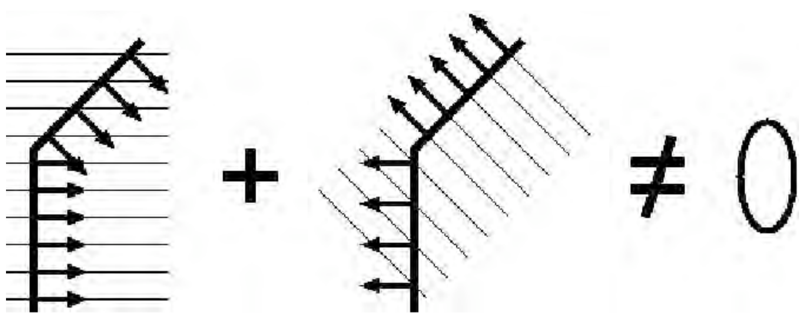


Fig17 Cross section of IMARI-fragment / Fig18: List structure of the cross section

Thinning operation: The Thinning operation of 3-D shape is very difficult. However, because the cross section of this research is special 3-D shape, we do thinning operation under the specific condition. Because a cross section is extracted from the normal vector on the surface of the fragment model, the cross section is the thin 3-D shape of the thickness 1 pixel. We construe the cross section as quasi 2-D shape. The thinning operation extracts the equidistant line from the both edges on the cross section.

Cross section matching rule: We search corresponding cross sections of fragments using the normal vector and the list structure of cross section. A pair of cross sections is tested if their list structures are matched each other, and a pair of cross sections is matched when the summation of the normal vectors in one cross section is approximately equal to another one as shown in Figure 19. Because the summation of the normal vector changes each other by the measurement direction of the slice image as shown in Figure 20, we change a unit normal vector to the summation of the normal vector in proportion as around area.



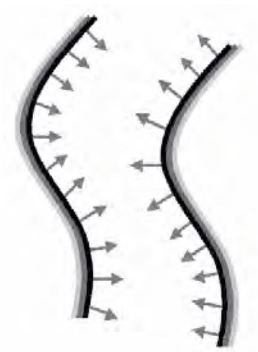
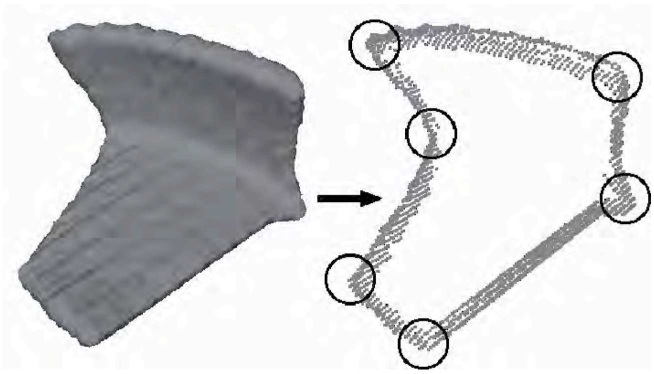


Fig19 Cross section matching rule / Fig20: Error in direction of the slice image

Cross point definition: 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 21. 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 22, 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. At the present stage, we specify a point by the handwork. But, this process will be automatic pretty soon.



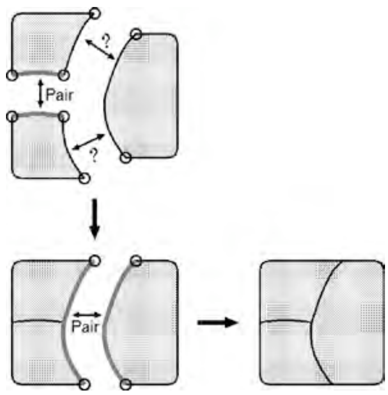


Fig21 The cross point / Fig22 The order of a counter part

Searching a counter part using cross points: Following are concrete process of searching a counter part.

Using the list structure of the cross section of all fragments, we measure the curve distance of the cross section which was caught to the cross points as shown in Figure 23.

If a pair of curve distance values is in error by less than 5%, we compute the summation of the normal vector on the each cross section.

If a pair of summation of the normal vector is in error by less than 5%, we do restoration task using the cross section matching rule as shown in Figure 24.

By setting the straight line which links corresponding cross points to the turn axis, relationship of the corresponding cross section becomes a one degree of freedom. So, we can confirm easily whether or not checked normal vector is corresponding cross section.

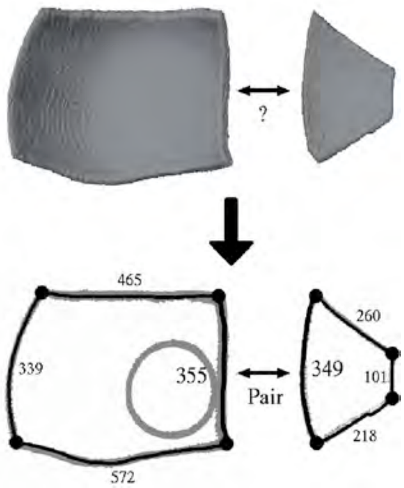


Fig23 Searching a counter part using cross points / Fig24: Matching a counter part using cross points

Example of automatic restoration using cross points: We tested automatic restoration by searching the corresponding cross section using the cross point. We use the IMARI-cup that the number of the searching fragments is eight. First, we measure the curve distance of all fragments cross section which is caught in the cross point. The numerical value written in the Figure 25 is the distance value of the cross section. Because the right corresponding cross section can not be searched, we cut off a sufficiently short distance value. We defined this threshold value as under 100 pixels. Next, among the cross sections to have a near distance value, we compute summation of the normal vector on the each cross section. And, we do restoration task using the cross section matching rule.

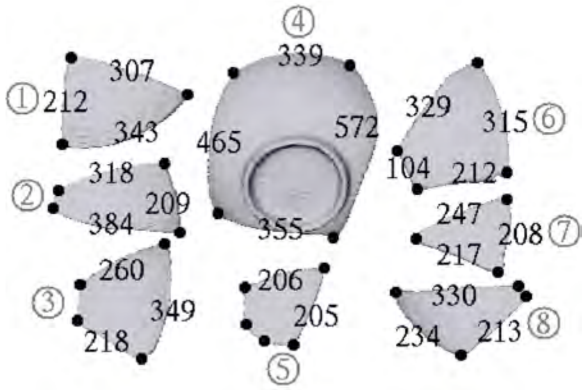


Fig25: Automatic restoration of IMARI-relic 1

When the automatic processing to all cross sections of all fragments is conducted, the computer outputs 19 combinations. When pairs of the fragments with different thickness are excluded, 5 combinations as shown in the figure 26 are obtained. When the cross points of fragments are reoriented, a new distance value of the cross section is found and as a result new combinations as shown in the Figure 27 are discover. Considering the fact that the false combinations are included in the pairs shown in the Figure 26, the result as shown in the Figure 28 is obtained.

Fig 26 Automatic restoration of IMARI-relic 2 / Fig 27: Automatic restoration of IMARI-relic 3

Fig 28 Automatic restoration of IMARI-relic 4

Estimating the automatic restoration result, as errors are accumulated as the processing proceeds, a big crack may be generated somewhere. Because however, we can expect the whole shape and rectify easily by the restoration system, as the total, the restoration task is very easy. We could get a similar result about the other relics. The quality of automatic restoration will be improved if the information including the number assigned to each fragment and the arrangement of the fragments recorded at the excavation would become available. At present, all corresponding cross sections are always discovered with the system even if all cross points are detected. In the case we have to give a pair of candidates to make the system examine the possibility of correspondence between them. This semiautomatic restoration task seems tedious to us, but it is very efficient because quite a bit of task to find pairs of fragments is done by the system.

4. CONCLUSION

A new approach is proposed in this paper that automatically restores a surface model of a fragment with a complicated shape from the X-ray CT slice images. The fragment model generated from X-ray CT images requires neither complicated CAD operation nor the intervention of man. The method proposed makes it possible to automatically restore surface models of objects with complicated shapes. Compared with the single-face model restored with a laser measurement, it is quite easy for us to propose candidate pairs to be matched to the system, because a stereoscopic spatial effect allows us to grasp the shapes of fragments and the efficiency of the restoration task to be improved. Making the best use of the thickness of a fragment leads us to the possibility of the automatic restoration that exploits information such as cross sections and the cross points, which are easily got from restored 3-dimensional fragments. At present the quality and precision of restored relic with the automatic restoration system shown in this paper is inferior to those of restored one with manual operation. Only the shape information is used to restore a relic. The materials composing a fragment, which can be detected with a multi-spectrum device, and the color or pattern on it will contribute to the improvement of the performance of the automatic restoration system. If the distribution of fragments in the exhumation sit is available, it will contribute to narrow the possible combination of fragments that match each other. In reality, archaeologists who excavate relics depicted the exhumation site. Instead of drawing the site, taking a photograph of it will help the system find pairs of fragments

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