Cutting operation of virtual object and its application to medical simulation

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Abstract

In this paper, we propose a cutting operation that is one of the shape transformation. The technical applicable field is wide and includes a molding task or an operation simulation. We realize the system with cutting operation function. The system permits us to cut the surface model into free forms in virtual space. As an application in the medical field, we apply the system to the brain surgery operation. We show the result that is obtained by applying the cut operation to restored cranium model. We describe some problems are found through experiments.

Key words: cutting operation, virtual object, medical

1. Introduction

By showing the information that has been made by a computer directly to the human sensory organ, the technique having the active experience in a virtual world possible attracts attention. Cutting operation is one of the fundamental operations used for a molding task and a surgical operation. It is difficult to realize cutting operation in the virtual space, thought it is an easy operation in real space. As the realization technique, there are two methods based on a dynamic approach and a geometric approach. As the former is to destroy the minute region of an object by the stress concentration, it is difficult to simulate it dynamically. On the other hand, a geometric approach is the procedure that aims at the shape of the material formed as the result of an operation, and various procedures are suggested including the set operation. Basic concept with the geometric approach in this research, the system that permits us to cut a virtual object into arbitrary shapes is developed. Next, the simulation system for a surgical operation is realized. The operation of craniosynostosis is adopted as the example of the surgical operation. Because numbers of cases and surgical operation examples are extremely few, surgical operation experience is hard to be accumulated. It is thought that the simulation of such a rare example is useful for a doctor.

2. Basic concept

2.1 Tool

As tools for cutting an object off in the real world, there are various objects such as a knife, scissors or a laser scalpel. For example, most people will use scissors to cut a sheet of paper off. But there is no person who uses scissors to cut a fruit. In this way, the tool exploited depends on the object to be cut. When we cut an object off in a virtual reality system, both the input equipment and output equipment are different based on what is assumed as a tool. For example, the scissors are operated by a manual operation. In order to simulate it in a virtual world, the Instrument such as a data glove reflecting the movement of a hand will become necessary. The result that the sense of reality is increased by using 3-dimensional input equipment is reported. On the other hand, in the deformation operation such as a cutting, the more complicated the material becomes, the more the calculation cost for examining the interference between objects increases.

In this research, any special input equipment is not exploited but a mouse is used. Mouse cursor moving on the 2-dimensional plane on a display can be regarded as a virtual laser scalpel.

2.2 Method of expression 3D objects

According to the survey studied up to now, a voxel model is used to visualize the process and result of cutting operation. The advantage to use a voxel model is that a simple algorithm that the voxel of the portion interfered with an edged tool is erased can express the cutting operation. Another advantage is that the process of the cutting operation is observable with the progress of the edge of a blade. A surgical operation simulation for cutting a bone[3] or a virtual sculpture is well known

as examples aiming at this advantage. But the expression using the voxel model is so difficult to express the smooth face of an object that the quality of face geometry becomes a problem. Although the improvement in the quality of face geometry can be attained by making the unit lattice of a model fine, it causes both data volume and processing time to increase. Consequently, a polygon model is used in this research.

A polygon model is used as the means for defining the shape of an object in a virtual reality system. The reason is that the computer equipped with some exclusive hardware to draw polygons at a high speed makes a real time display possible. As the research aiming at polygon models, the cutting operation in a virtual reality system is known[2].It is the system which will form a complicated model by cutting a simple cube mode, and is realized using set operations. This research also applies the set operation.

2.3 Cutting a polygon model

A polygon mode means a modeling method to approximately express curved surfaces using polygons in which a normal vector is defined. Cutting operation for an object described with a polygon model is generally realized by dividing the polygons constituting the object into two groups along the cross section. But the process to set up a new polygon on a cross section is necessary to cut a dense model. It is thought that the shape of a cross section is equal to the geometric locus of the edge of a blade.

When a chip of wood was cut off using a saw in a real world, the volume of the chip of wood should decrease as chips occur with the operation. But computation becomes complicated when it is considered. The reason is that parameters such as materials of an object and the edged tool must be considered. This point is not considered in this research for the reason.

3. System configuration

A high-speed graphics workstation OCTANE and Open Inventor are used for the implementation of the system.

3.1 Data structure

Polygons constituting a model are defined with the coordinate values of vertices. The edge of a polygon is implicitly defined with the two vertices. The adjacent polygons share an edge and two vertices. As the Open Inventor has the function to draw the set of polygons with shading, any surface model can be easily drawn using this data structure. It is, however, insufficient to

realize a cutting task. As every polygon exists independently from others in the simple data structure of polygons, it is difficult to express the information on the relevance between the polygons. So it cannot effectively express the information associated with the relevance between polygons as follows.

to refer polygons adjacent to a peculiar polygon

to examine polygons sharing a peculiar point

to retrieve a pair of polygons sharing a peculiar edge

Consequently, a data structure to manage the relevance is made for this system. This data are made for every polygon. Table 1 shows the details of the data structure.

Table 1. Data Structure

Polygon data	List of indexed vertices of Each polygon
Connection data	List of indexes of adjacent polygons
	Common vertex and edge
	Link to other connection data
Flag Data	Used in processing

4. Procedures of virtual cutting operation

The system is implemented in the following procedures.

4.1 Generation of cutting line and cross sections

First, a cutting line and a cross section are drawn in the experimental system. Next, calculating intersection points and the models generated with the cutting operation are reconstructed. While the mouse is pushed, the coordinate data are acquired to get cutting line and a cross section (Fig. 1 (a)) As shown in the Fig. 1 (b), the coordinates At, Bt, Ct, Dt of the points A, B, C, D are calculated where a Laser beam intersects the surface of the object. The cutting line is expressed by connecting At and At-1, Bt and Bt-1 respectively, and the cross section is defined as the face enclosed by the four points. Here note that the point must be interpolated where the edge of polygons constituting the object and the cutting line segment.
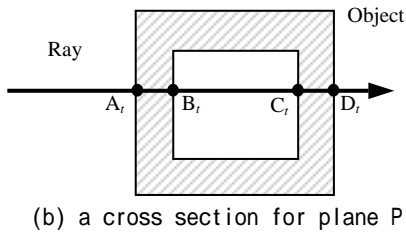

(a) Cutting operation

(b) a cross section for plane P
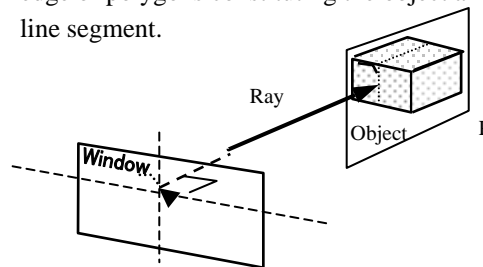
Fig.1   Generation of cutting line

4.2 Interpolating crossing points

This is the process getting an intersection point between the edge of the polygon constituting a model and a cross section. Cutting point data acquired during the cutting operation are discrete. In the case when a cutting plane line moves to the next polygon, the point on the border line may not always be acquired. That is, line segments (P2P3, P4P5, Q2Q3, Q4Q5) go through the model. (see Fig.2(a))

Consequently, the point on the common edge between the adjacent polygons must be found so that the distance between the line segment and the point is made minimum. As the result, the set of the points P6, P7, Q6, Q7 are found. Then the vertex data of the cutting plane line and the cross section are revised (see Fig.2 (b)).
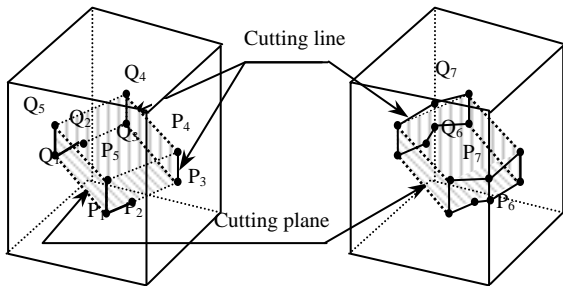

(a) before processing   (b) after processing
Fig.2   Interpolating crossing points

4.3 Division and reconstruction of faces

Assume that we cut off three polygons D, E, F along a cutting line as shown in the Fig. 3 (a). Then the polygon D is divided into two polygons D1, D2 as shown in the Fig. 3 (b). After D1, D2 are divided into triangles, respectively as shown in the Fig. 3(c), if they are collected based on the adjacent relation, two polygons (A,B,C,D1), (D2) will be obtained. Two fragments (A, B, C, D 1, E 1, F1) and (D2, E2, F2) can be obtained by dividing the polygons E and F in the same way.
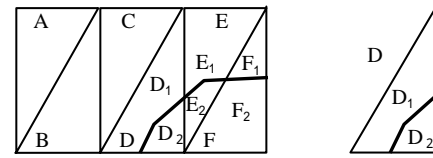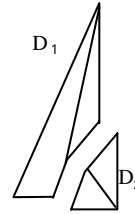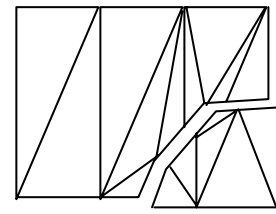

Fig.3   Division and reconstruction of faces

5. Apply the system to the surgery operation

5.1 Craniosynostosis

The cranial stenosis is the generic name for the deformity that norma facialis anamorphosis becomes obvious with aging as the cranium does adhesion early. Physician diagnoses it using the appearance of a patient and consecutive 2-dimensional images provided from medical instruments such as CT scanner/ MRI and operates if an operation is needed. He cuts the adhesion department off in the operation and the caput skin is covered after arranging the cranium pieces so that they are never overlapped. Physician must perform the operation thinking about the resultant appearance of the patient after the operation.

5.2 Concept of operation simulation system

We are aiming at the system helping the visualization of the head shape after the operation as it is difficult predict the result in the cranial stenosis operation. The following items are the functions pursued in the system.

3-dimensional reconstitution of lesion data Ablatio operation
Compound suture operation
Bending anamorphosis operation
Displacement operation (relocation operation)

These operations are the typical ones that are done in a real operation.   We want to implement the system allowing a physician to relocate bone tips referring to the normal cranium model. The compound suture and bending anamorphosis are not realized yet.

5.3 3-dimensional restoration

The procedure for restoring a 3-dimensional model from medical data is called a 3-dimensional restoration. Many approaches have been attempted as the technique of 3-dimensional restoration. They can be classified roughly into a surface restoration and a volume restoration. The surface restoration means the method to gener-

ate a surface between the corresponding pair of outlines extracted from consecutive medical images On the other hand, the technique using voxel is well used in the volume restoration. As examples with the surface restoration method, the research on an automatic restoration of the cranium model [5] and that of a relic [6] are well known. The restoration of the cranium model is performed referring to these examples.

5.3.1 The threshold process for CT images

The threshold process is practiced using the characteristic that the CT value corresponding to bones holds the biggest value in every tissue. The smallest CT value in the range (100-150) regarded as a bone is selected as a threshold. A contour is extracted by detecting the edge of the provided binary image. These processes are repeated for all sliced images.

5.3.2 3D effect process

First of all, a plane is put on the contour of the bottom layer shown in the Fig. 4 (a). A four-sided face is put on the two consecutive points on a contour and the corresponding two points on the next contour (Fig. 4(b), 4(c)). The same operations are repeated until the top of the head is reached.

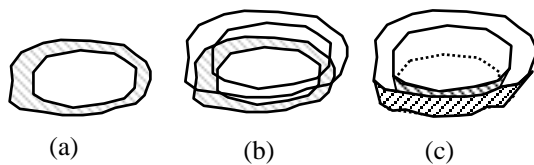| | | |
| (a) | (b) | (c) |

Fig.4　Reconstruction of a surface model

5.3.3　Example of The re-constructed cranium model

The reconstructed cranium model is shown in the Fig. 5 in this method
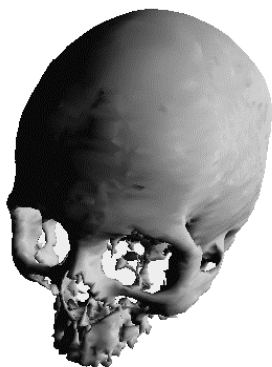

Fig. 5　Reconstructed cranium model

5.3.4 apply the cut operation to the restored cranium

The result is shown in the Fig. 6. that is obtained by applying the cut operation to the restored cranium.
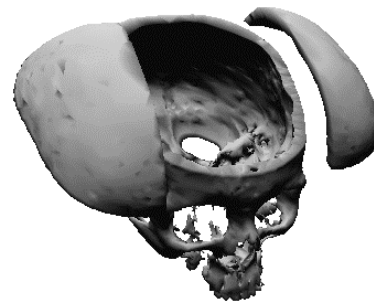

Fig. 6　An example surfaces model

6. Conclusion

In this research, virtual cutting operation was realized and the application to the simulation system of a surgical operation was examined. A mouse is assumed to be a laser knife and the technique for cutting off objects in a virtual space into arbitrary shapes was proposed. The polygon model was used for describing virtual objects. The operation of craniosynostosis was adopted as a surgical operation example and the 3-dimensional re-structuring of a head model was realized. Next, an experiment to cut off the model in arbitrary shapes was shown.

The following problems are found through experiments. At first, the speed of the cut operation must be raised. The restored model of a head is so complicated that it needs many polygons. This increases the time necessary for the cut operation. When the real object to be cut becomes complicated, the real cutting operation becomes also so cautious that it takes long time. This means that an extremely high-speed cut operation is not necessary for the medical surgery simulation. The examinee experiment by many doctors is, however, necessary to verify the validity of this system.

Next let us examine fundamental elements as a simulation system. The followings are necessary. When a cut operation was not successful, it must be possible to invalidated the effect, or to make a repeat from an arbitrary point. In addition to the above, the followings are necessary.

On the other hand, unexpected pieces are included in the model restored from real data. The cause is followings; there is much space as a cavity inside bones including the skull. A CT value is disturbed with the influence of metals embedded in the treatments of a tooth, and it appears in the CT image as noise. Such noise causes complicated shapes to the image in the automatic restoration. It is possible to prevent the gen-

eration of such complicated shapes by filling the part in a binary processing instead of restoring such a cavity. If the numbers of polygons are reduced together with the noise reduction, the restoration of beautiful models will become possible. In addition to the problem of a model, it is the greatest subject to examine the fundamental operation as a simulation system. For example, let us consider the bending operation which is another fundamental deformation operation. In a bending operation in a real world, the amount of the deformation is controlled by changing the force added to the point it is applied Polygon corresponding to point of application (face) is decided To realize the bending operation that is another fundamental deformation operation.

To map the texture of a face skin to the cranium relocated.

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