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Interactive Three-Dimensional Free-Form Modeling

Hiroshi Kaizuka[*1] Makoto Sagara[*1]

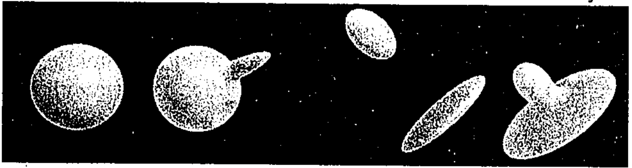
Abstract:

Research on a new technique of interactive three-dimensional free-form modeling is presented with attention focused on the modeler's functions. The research aims at developing a modeler that can design the form of a three-dimensional object of arbitrary topology without alignment or coordinate calculation, while visually checking the changing form of the object. At the present stage, the modeler is complete only in its most basic part, but is functionally capable of designing such forms that cannot be easily constructed by any other existing modeler.

1. Introduction

The basic goal of the proposed modeler is to realize the following four functions on a single mathematical principle, as schematically illustrated in **Fig. 1**:

CG-CLAY: Local deformation of form CG-CLAY: Fusion of two objects



CG-CLAY: Change in topology of form CG-CLAY: Guarantee of smoothness of form

Fig. 1 Target functions of modeler

(1) Local deformation of form: The user can locally deform the region that he or she wants to deform.
(2) Smooth fusion of two objects: Two objects are separately constructed and then fused into a single object like clay.
(3) Change in the topology of form: The topology of a three-dimensional object is freely changed for instance by opening a hole in or attaching a handle to the object.
(4) Assurance of smoothness in form: The form of a three-dimensional object is kept smooth through the process of deformation.

It is extremely difficult to attain these objectives for modelers using such parametric patches as normally used in CAD.

The modeler developed through the research adopts a method that does not use parametric patches. Instead, it basically employs an implicit function modeling method whereby a three-variate polynominal $f(x, y, z)$ is constructed and the form of a three-dimensional object is defined by $f(x, y, z) = 0$.

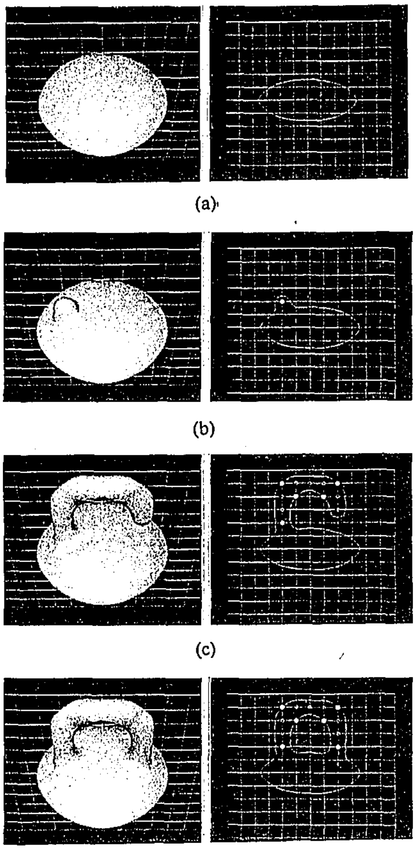
2. Functions of Modeler

2.1 Basic operation

Two most basic deformation operations for local deformation of forms are introduced here. In **Fig. 2**, the ellipsoid is the starting form, and a handle is formed on the ellipsoid by continuous pull operation. The topology of a three-dimensional object is changed by the last deformation operation. In **Fig. 3**, a hole is made in an ellipsoid by prod operation. In this case, too, the topology of the three-dimensional object is changed by the last deformation operation. In each operation, the form of the three-dimensional object is C^1 continuous all over. In other words, the tangent plane at each point continuously changes.

The current version of the modeler deforms objects by selecting the part to be deformed with the mouse on the cross-sectional view of the object as shown on the right-hand side in **Figs. 2** and **3** and by specifying the amount of deformation with the mouse. In these figures, a yellow circle denotes that the region in question is deformed with intensity 1, and a green circle is for a region deformed with intensity 2.

[*1] Technical Development Bureau



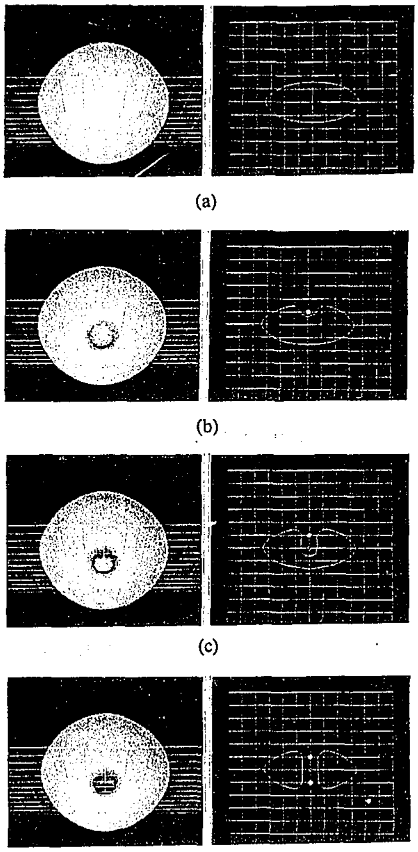
(a)

(b)

(c)

(d)

Fig. 2 Basic deformation (pull deformation)



(a)

(b)

(c)

(d)

Fig. 3 Basic deformation (prod deformation)

2.2 Sample sculpture

Some sample sculptures made by the modeler are given below:

Fig. 4 shows a sample sculpture of a "demon." A principal characteristic of the modeler is that it can easily construct a three-dimensional object composed of free form surfaces. In particular, there is a hole in each earlobe. This is an accomplishment that owes to the change of topology through local deformation, one function of the modeler. This sculpture, it should be noted, was rendered by hardware Gouraud shading after polygonal approximation for high-speed drawing.

Fig. 5 shows a sample sculpture of a "hand." If such a form is to be constructed by a technique using intensity primitives like meta-balls, the fingers tend to stick together as the intensity primitives are liable to fuse. With the proposed modeler, one need not be concerned much about this tendency. This is because the modeler, by using algebraic surface patches, localizes the scope of influence of the implicit functions that define objects.

Fig. 6 shows "die" design. Each side of the die is strictly constructed. That is, it is composed of planes, which is worth noting. Since geometrical smoothness is pursued, however, each corner is bound to be rounded where its sides meet. This is one drawback of the modeler.

Fig. 7 shows an "apple" design. The modeler can represent such a wholly smooth object as an apple. It is very difficult to construct such a form by repeating local deformation. Some global deformation approach must be made. Global deformation is the most important issue for the future modeler.

2.3 Application to three-dimensional visualization of volume data

Lastly, the following is a case of modeler application to the problem of cutting out a target three-dimensional object from plural sheets of computer tomography (CT) data. **Fig. 8** shows a hipbone reconstructed by use of the modeler. **Fig. 8(a)** is for a hipbone reconstructed from CT data after thresholding, and **Fig. 8(b)** is for one after both thresholding and smoothing.

3. Conclusions

The modeler is still in the stage where only its most basic parts are implemented on a graphic workstation. Many problems remain to be solved. The most urgent one is the development of a global deformation technique as noted in Chapter 2. This question has always been an important issue in the world of CAD, and its complete solution is still to be seen. Research on high response combined with handy global deformation approach is a challenge we cannot circumvent.

Acknowledgment

The CT data used in **Fig. 8** were furnished by Professor Jun-ichiro Toriwaki of Information Engineering Department, Faculty of Engineering, Nagoya University.

Fig. 4 Sample sculpture (demon)

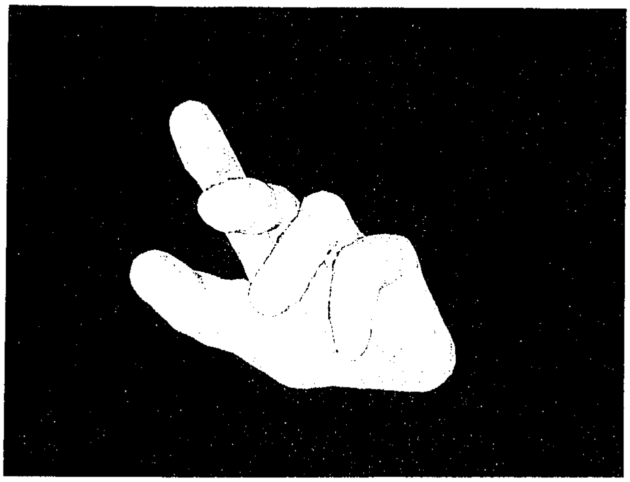


Fig. 5 Sample sculpture (hand)

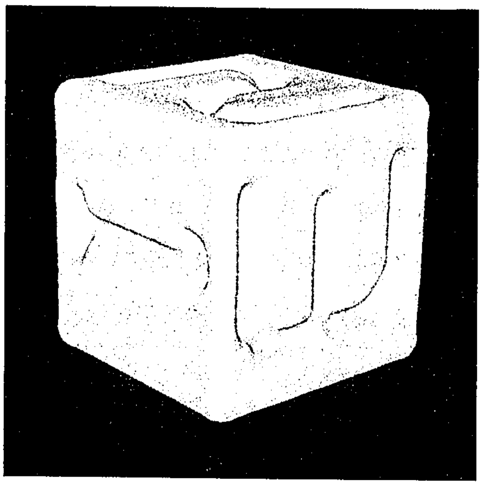


Fig. 6 Sample sculpture (die)

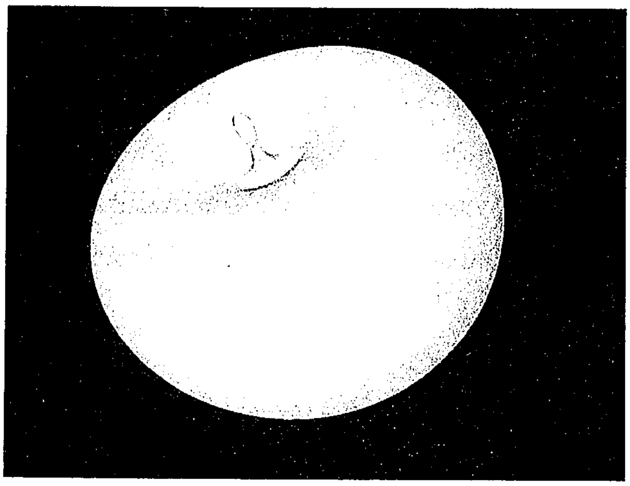
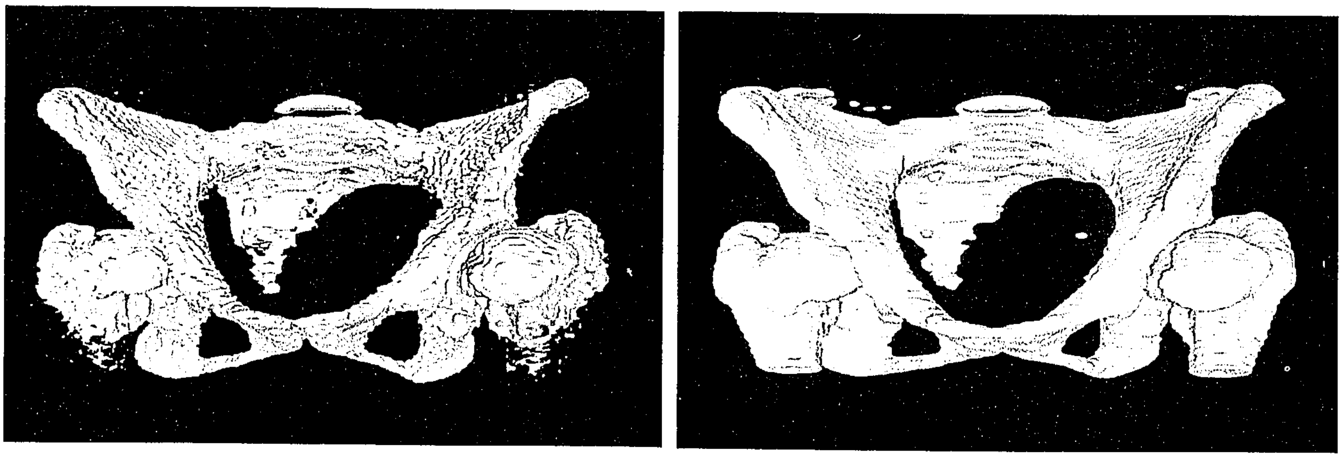


Fig. 7 Sample sculpture (apple)



(a) After thresholding

(b) After thresholding and smoothing

Fig. 8 Application to three-dimensional visualization of CT data