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A Development of Dynamic Deforming Algorithms for 3D Shape Modeling with Generation of Interactive Force Sensation

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Abstract

Recently, the necessity of development of virtual reality technology has been highly increased in various fields. Especially in creative activities such as the design of industrial products, virtual reality technology enlarges ideas of designers if the designers can directly manipulate objects in virtual space just like in the real world. As a result, the efficiency of product development can be highly improved. In such activities, it is not too much to say that the most important operation is to deform shapes of virtual objects. And to realize the efficient and comfortable manipulability, it is desirable to show not only visual but also force sensation. In this paper, we propose the algorithm which enables deformation of virtual objects easily, inspired by tasks of carving an image in wood. In this method, the deformation is carried out by not moving points on the surface of virtual object but generating and/or vanishing points around the contact area. Thus we can easily generate various shapes with a reasonable feedback force.

1. Introduction

Thanks to the recent remarkable development of computation ability, we have been able to manipulate complicated 3D shape information easily. Usually the information flow between operators and computers, however, is done using mouse, keyboard, CRT and so on, thus the necessity of developing more interactive interface has been highly increased.

Virtual reality technology[1] is expected to give new paradigm to this problem, and enables comfortable and efficient interaction by stimulating various sensations. Especially, force sensation[2][3] is important for direct manipulating of virtual object in creative activities such as design of industrial products.

These days, due to the various needs of consumers, the industrial world has been obliged to decrease time and cost in the stage of product development. The efficiency of development can be highly increased since the ideas of designers can be realized immediately if they are able to manipulate virtual objects as in the real world. From the above consideration, we think that deforming shapes of virtual objects is the most important operation for the above-mentioned activities.

In virtual reality technology, studies on shape deformation have just started, and the following methods have been reported:

Krueger[1] proposed the deformation method by indicating the controlled points of spline curve fixed to an operator's fingertips. Hiraike *et al.*[4] proposed another deformation method by cutting off portions of a virtual object using a virtual cutter . In these methods, however, it is difficult to generate interactive forces. Another interesting approach was proposed by Sato *et al.*[5]. They developed the concise deforming algorithms under the physical the condition of constant volume of a virtual object. But this method has a serious flaw whereby generated shapes are limited to symmetrically rotating ones. In this research, we developed dynamic deforming algorithms with reasonable interactive force sensation from the standpoint of three-dimensional shape modeling, inspired by carving an image in wood. In this method, the deformation of virtual objects is carried out by not moving points on the object surface but generating and/or vanishing points around the contact region. And the feasibility of our proposed method was confirmed by simple simulations.

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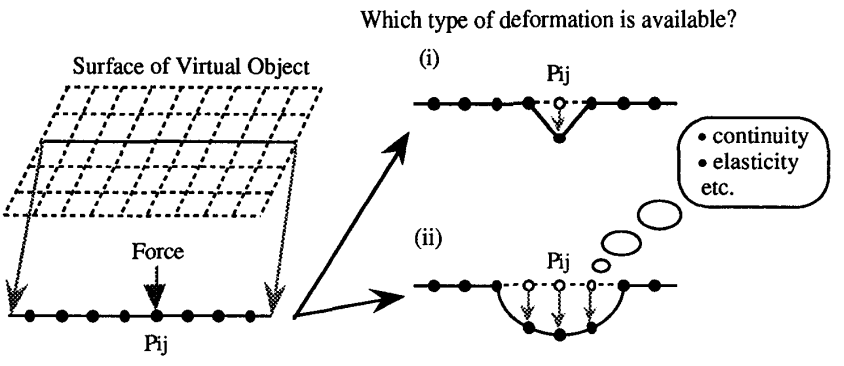
2. Proposed Algorithms

2-1. How Do We Deform a Virtual Object?

First of all, we must determine how to describe and deform a virtual object. We investigated this problem using a surface model as a practical example.
Fig.1(a) shows a portion of the virtual object surface, and solid discs denote nodal points on the surface. Let us consider how to deform this model when we apply force at P_{ij} from top to bottom. Fig.1(b) shows two types of deformation method. (i) demonstrates the deformation by moving only P_{ij}. In this figure, empty and solid discs represent nodal points before and after deformation, respectively. In this method, the deformation is carried out by moving only one point. Thus if we want to construct a complicated-shaped object, it needs enormous operating interactions.
On the other hand, (ii) shows another method where deformation is applied around P_{ij}. But to realize a reasonable deformation, this method tends to be complicated since the deformation must satisfy the physical constraints such as continuity, elasticity and so on. And it is doubtful whether the deformation in the virtual world must be exactly the one in real world for 3D shape modeling. Moreover, both methods have serious problems whereby it is difficult to generate demands of interactive force.
Therefore, the characteristics which are necessary for the description of virtual objects can be best summarized in the following sentences:(i)we can deform the initial shapes of virtual objects into arbitrary ones, (ii)in real time and (iii)we can generate demands of reasonable interactive force sensation.



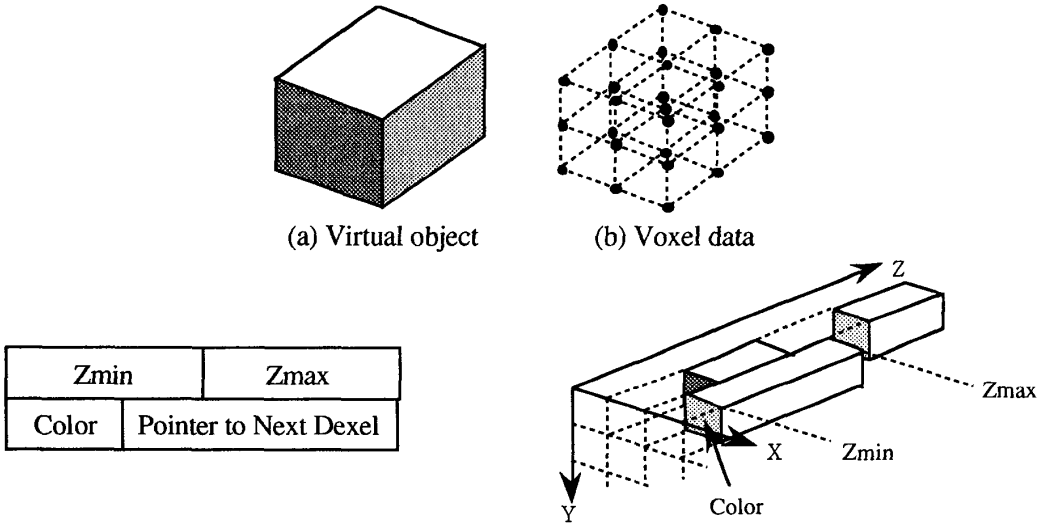
(a) Before Deformation (b) After Deformation

Fig.1: Methods of Deformation.

2-2. Description of a Virtual Object

From the above consideration, we decided to describe the virtual object by not using the surface model but the collection of points, namely voxel structure, as shown in Fig.2. By using this description, we have no need to consider the movement of nodal points on an object surface in the case of deformation. Moreover, we can easily generate reasonable interactive feedback force (as mentioned in later section).
As for general voxel models, however, we must store voxel data not only on the surface but also inside virtual objects. Assuming the virtual object as shown in Fig.2(a), the structure of voxel data to represent the object(voxel model) would be the one shown in (b). Note that each solid discs denote voxels. Thus the size of structure will be explosively increased according to the one of voxel model. To overcome this obstacle, we use the dexel structure[7] as shown in the same

figure(c). Where Z_{min} and Z_{max} denote the minimum and maximum values of Z-buffer, respectively. And color indicates the one on the visual portion at each pixel(see (d)). By using this structure, efficient description of the virtual object can be realized.



(a) Virtual object (b) Voxel data

(c) Dexel (d) Description of virtual object

Fig.2: Method of the Object Description.

2-3. Virtual Finger

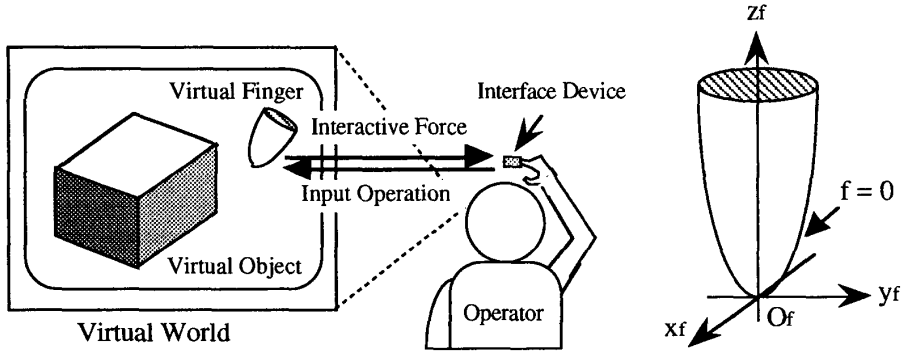


Fig.3: Virtual Finger.

Taking account of the comfortable interaction for operators(designers) in deforming, we use a virtual finger as an operating device.

Since the interaction between the virtual object and virtual finger must be carried out in real-time, we represent the virtual finger using a paraboloid expressed as:

$$f = z_f - K_s(x_f^2+y_f^2), \tag{1}$$

where K_s is a positive coefficient, which determines the shape of the virtual finger.

Fig.3 shows the relationship between the virtual object and the virtual finger. By using this representation, we can judge the contact between the object and the finger quickly from the sign of

the function f. Moreover, we can vary the shape of virtual finger according to tasks by changing only one parameter K_s.

2-4. Principle of the Proposed Method

(a) Contact Judgement

To construct good interactions between operators and virtual space, we must consider contact judgement. Note that the virtual object and finger are represented by the different coordinate systems: O_b-$x_b y_b z_b$ and O_f-$x_f y_f z_f$, respectively. O_f-$x_f y_f z_f$ is attached to the fingertip, and it moves according to the virtual finger. On the other hand, the virtual object is represented by the coordinate system O_b-$x_b y_b z_b$ fixed to the virtual space. For the contact judgement, we firstly transform $\boldsymbol{f}$ expressed in (1) to be represented in the virtual object coordinate system as:

$$\boldsymbol{f}^b = \boldsymbol{A}\boldsymbol{f}, \tag{2}$$

where $\boldsymbol{A}$ is the transform operator from the coordinate system of virtual finger to the one of object, and is determined by measuring the position of the operator's fingertip. After the above transformation, we can easily judge the contact between the virtual object and finger by the substitution of each voxel $\boldsymbol{x}^b$ into the virtual finger function expressed in (2) as:

(i) if $\boldsymbol{f}^b(\boldsymbol{x}^b) > 0$ then contact exists
(ii) otherwise no contact.

To realize the efficient and comfortable environment, we must calculate the above procedure quickly. Therefore, we avoid unnecessary contact judgement by devising the data structure of the point in a virtual object.

(b) Deformation Method

Fig.4 shows the proposed deformation method. In the same finger (a), empty discs denote the points(voxel) of the object inside the finger after moving the operator's fingertip. Deformation is carried out by vanishing these points. In this method, we can easily deform the object because there is no need to move the nodal points.

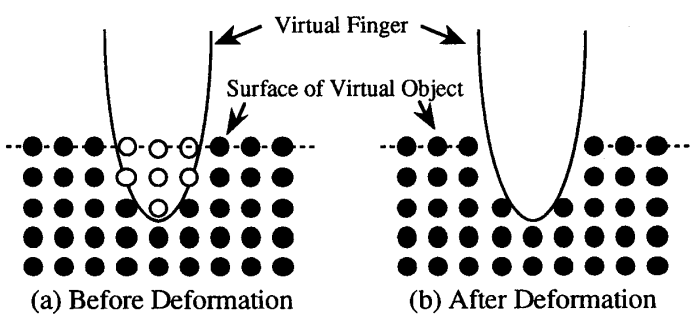


Fig.4: Proposed Deformation Method.

(c) Calculation of Interactive Forces

When we deform the virtual object, it is important to give interactive forces to operators for the efficiency of tasks. Fig.5 schematically shows the relationship between the virtual object and finger in a deforming task. In the same figure (a), the virtual fingers denoted by solid and dotted lines represent the states before and after moving, respectively. Empty discs are the points which come into the fingers after moving. And the vector $\boldsymbol{P}$ denotes the moving direction, which can be easily derived, using the relationship between the previous and current positions of the virtual fingertip.

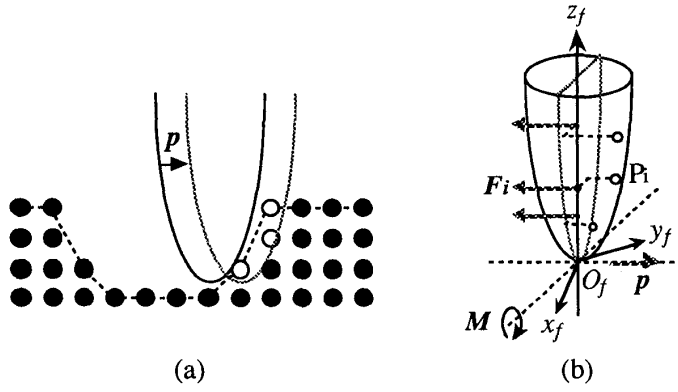


Fig.5: Generation Method of Interactive Forces.

The problem which we must consider is to determine how to generate reasonable interactive forces using these points inside the virtual finger. In this paper, as shown in Fig.5(b), we derive interactive force $\boldsymbol{F}$ and moment $\boldsymbol{M}$ which are affected at the fingertip using the number and position of the points inside the virtual finger as follows:

$$\boldsymbol{F} = \sum_{i=1}^{K} \boldsymbol{F}_i = -K_f K \cdot \frac{\boldsymbol{p}}{|\boldsymbol{p}|} \tag{4}$$

$$\boldsymbol{M} = \sum_{i=1}^{K} z_i \times \boldsymbol{F}_i , \tag{5}$$

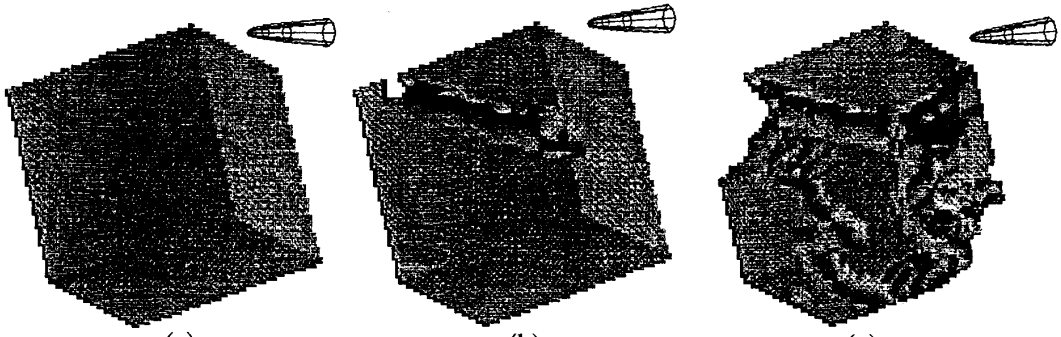
where K_f is a positive coefficients, which gives the stiffness of the virtual object. K denotes the number of points inside the virtual finger, and z_i represents the position of the point $\boldsymbol{P}_i$ inside the finger in z axis. Note that we do not consider the momentum around z_f axis. Therefore, we need 5 degree-of-freedom for virtual finger interface device. We are now constructing the interface device using the mechanism based on the work of Iwata et al.[8].

3. Experimental and Simulation Results

As a rudimentary stage of this research, we carried out simple experiments and simulations to confirm the validity of our proposed method. Since the motor-drive circuits of our interface device are now under construction, the validity of the generated interactive force sensation is carried out by simulations, whereas experiments with respect to the proposed shape modeling.

3-1. Shape Modeling

Fig.6(a) shows the initial shape of the virtual object to be deformed. Fig.6(c) demonstrates the final shape resulting from the deforming operations. From the figure, it is understood that we can deform the virtual object into arbitrary shape using our proposed deforming algorithms. Graphics are carried on Sun Spark Station 2/GS.



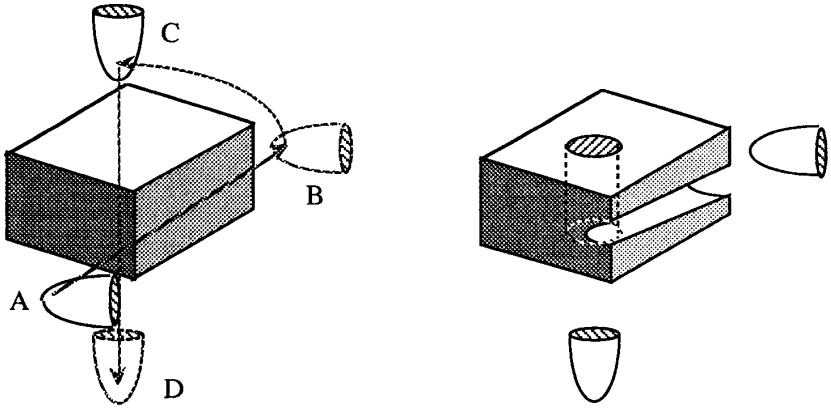
(a) (b) (c)

Fig.6: Experimental Results (Transition of Shape Modeling).

3-2. Evaluation of the Generated Interactive Forces

To evaluate the generated interactive forces, we carried out the following simulations:
Fig.7(a) shows the initial shape of the virtual object. We investigated the transition of the generated forces when we deformed the shape as shown in Fig.7(b) by moving the virtual finger in the order of A -> B -> C -> D. In this case, we assumed the following conditions:

(i) The position of the virtual finger between A and B remains horizontal, but vertical between C and D.
(ii) In the transition from A to B, we make the depth of scraping the object larger by degrees.



(a) Before Deformation (b) After Deformation

Fig.7: Procedure of Deformation.

Fig.8 shows the resulting generated interactive forces. In the same figure, the notations A, B, C and D on the horizontal axes correspond with the ones in Fig.7(a). The regions between A' and B', and C' and D' indicate that the virtual finger touches the object, respectively. In the figure, it is

observed that the value of moment is zero between C' and D'. This is due to the vertical position of the finger.

From the figures, the increase and decrease of the generated interactive forces correspond with those of the interactions between the virtual object and finger correctly, notwithstanding the simple method. Therefore our method can be expected to contribute to the efficiency in 3D shape modeling.

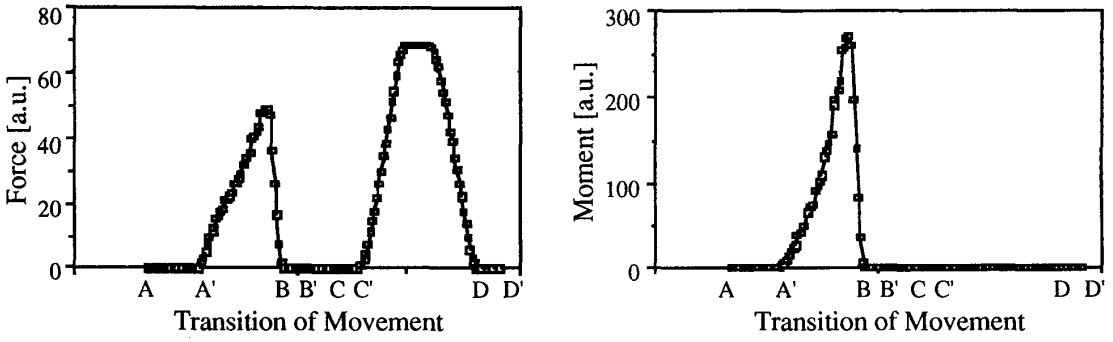


Fig.8: Transition of the Generated Interactive forces.

4. Conclusions and Further Works

In this paper, we investigated the algorithms which enable the dynamic deformation of a virtual object. To realize natural deformation observed in the real world, we must incorporate various physical constraints into the algorithms. But it is difficult to realize such deformation in real-time. Thus we deform virtual objects by not moving points but generating and/or vanishing points in an object, by inspiring the task of carving an image in wood. By using this method, we can easily generate reasonable interactive force sensation. As a rudimentary stage of this research, the proposed method was carried out by simple experiments and simulations. We are now constructing the experimental interface devices, and are planning to investigate the validity of our method quantitatively from the psychological aspects. And we will improve the algorithms to generate more and more natural sensations.

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