A Proposal of Free Form Modeling System with Force Feedback Based on the Strength of Materials

Wataru Wakita
Ehime University
Matsuyama, Ehime, Japan
wataru.wakita@ic.cs.ehime-u.ac.jp

Shun Ido
Ehime University
Matsuyama, Ehime, Japan
ido@cs.ehime-u.ac.jp

Abstract

We propose a free form modeling system based on the strength of materials. This paper describes a system which enables users to realize more intuitive and realistic modeling in attaching various material properties to virtual objects by means of haptic device with force feedback. This system presents different features of materials according to the attached material properties to the surfaces of virtual objects and by feeding back reaction force which derives from shape distortion. As a result, in the case that the virtual object is rubber, the system shows soft shape distortion, and in the case that the virtual object is metal, the system shows firm shape distortion. We conclude that our system makes free form modeling intuitive and realistic.

1. INTRODUCTION

3D modeling has been used for product designs, movies, computer games, construction product and landscape simulation and others according to the development of 3DCG technology. 3D modeler is needed in modeling of 3D objects. There are many kinds of modelers such as polygon, polygon patch, dealing with spline patch directly, sketch based modeling, specialized for virtual carving, metaball and particle etc. Mouse-based interfaces are usually used in the modelers. Moreover tablets, 3D device and haptic device are used in some specialized modelers.

However, material properties and stress to the materials are not strictly considered in conventional modeling tools. A particular material is assumed in clay modeling and sculpture modeling only.

So, there is a modeling tools of using haptic device as a means to solve this problem.

In this paper, we propose a free form modeling system based on the strength of materials. Various materials exsisting in the real world are applied to this system. As a result, in the case that the virtual object is rubber, the system shows soft shape distortion, and in the case that the virtual object is metal, the system shows firm shape distortion. Moreover, it is our expectation that this system is useful in assistance of the embodiment of an artistic sensibility and increasing of the creative impulse.

We have developed a prototype surface modeling system which enables user to realize more intuitive and realistic modeling in attaching various material properties to virtual objects by means of haptic device with force feedback.

2. RELATED WORK

The modelers dealing with polygon, polygon patch and spline patch directly have been developed such as 3dsMax(Autodesk, Inc.), Maya(Autodesk, Inc.), LIGHTWAVE3D(NewTek, Inc.), and SOFTIMAGE|XSI (Avid Technology, Inc.). Moreover, modelers such as Hexagon(Eovia Corporation), Silo(Nevercenter Ltd. Co), Modo(Luxology, LLC), and Rhinoceros(Robert McNeel & Associates) have been released. These surface modeling methods that deals with polygon, polygon patch, and spline patch make it possible for users to create complicated shapes.

Igarashi et al. developed Teddy(Igarashi 1999), a system that allows modeling of free form 3D objects from sketched 2D outlines. However, resulting models are constrained to a sphere-equivalent topology. Pixologic, Inc. developed a ZBrush (Pixologic, Inc.), a system that allows modeling free form 3D objects from sculptured surface models by virtual brush. This modeler enables sense that kneads clay by adding the ruggedness to a virtual object. SensAble Technologies, Inc. developed a Free Form(SensAble Technologies, Inc.), a system that allows interactive modeling free form 3D objects from sculptured volumetric models by 3D virtual brush with force feedback. This modeler enables more intuitive and realistic modeling that kneads clay by adding the ruggedness to a virtual object by PHANTOM(SensAble Technologies, Inc.) device. Haptic modeling and its associated technique are also well researched in recent years. However, material properties and stress to the

materials are not strictly considered in traditional haptic surface modeling.

3. SYSTEM OVERVIEW

Various materials such as rubber, plastic, glass, and stainless steel exist in the real world. It is our expectation that the realization of shape deformation such as such as press, pull, bend, and twist to these various materials satisfies more realistic modeling. However, it is difficult for only graphical rendering to represent the difference of these materials. To solve this problem, a haptic device is used for an input device of the shape and haptic rendering. Our system enables users to feel reaction force during deformation operation corresponding to each material properties based on the strength of materials. This system architecture is shown in Figure 1.
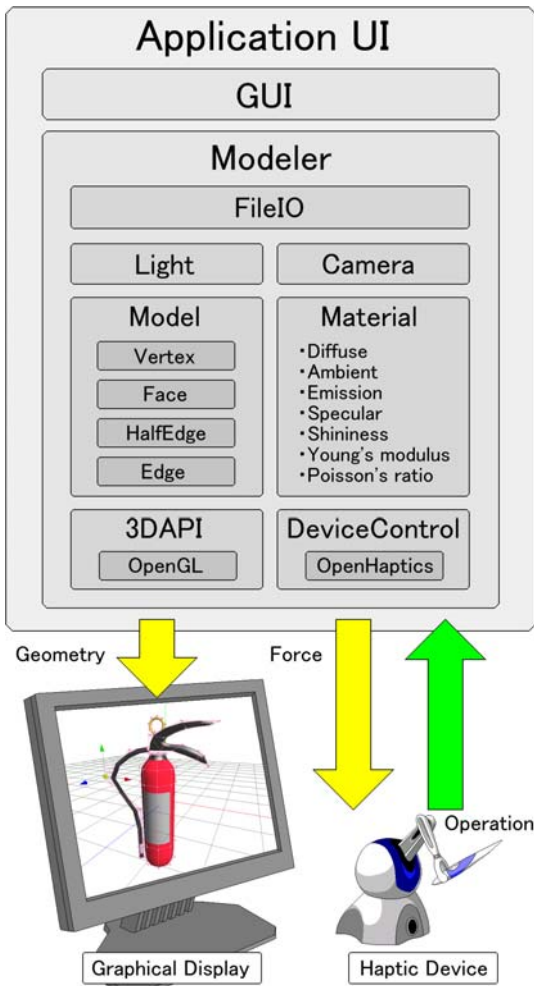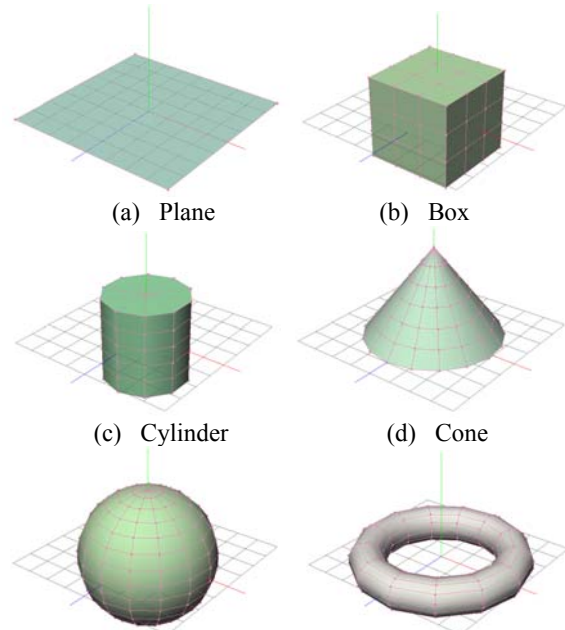
Our system is composed of an application UI, a graphical display, and a haptic device. The haptic device is used for operation of application, and haptic rendering. Graphical display is used for the graphic rendering. The surface modeler adopts using half-edge data structure(M. Mantyla 1984) as data structure. Currently, the system utilizes polygon and catmull-clark subdivision surface(D. Zorin et al. 2000) patch as a surface modeling methods(Figure 2). This system uses openGL as the 3DAPI and supports PHANTOM Omni as a haptic device. Plane, box, cylinder, cone, sphere and torus are available for the primitives in our system(Figure 3).

(a) Polygon   (b) polygon patch
Figure 2:Surface model

(a) Plane   (b) Box

(c) Cylinder   (d) Cone

(e) Sphere   (d) Torus
Figure 3:Primitives

Figure 1:System architecture

4. MATERIAL DESIGN

4.1 Extended Material

It is necessary that the surface characteristics are set to virtual objects in order to represent the surface properties. OpenGL generates the textures according to the following parameters of material properties normally.

- Diffuse
- Ambient
- Emission
- Specular
- Shininess

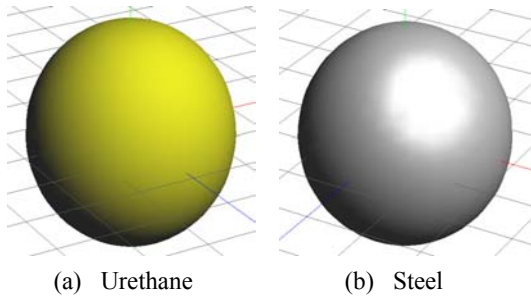Figure 4 shows the examples of surface properties of virtual objects which is adjusted by these parameters.

(a) Urethane　　　(b) Steel

Figure 4: Surface properties of virtual objects

The difference between urethane and steel are discernible in the reflection condition of light. However, it is difficult to present the difference between rubber and the urethane by only graphic rendering. So, we adopted the following parameters to conventional material properties

- Young modulus
- Poisson's ratio

These parameters make it possible to present various materials. For instance, these parameters of urethane and steel shown in Table 1.

Table 1: Material properties.

Material	Young modulus[N/mm^2]	Poisson's ratio
Urethane	50	0.4
Steel	206000	0.3
Glass	71600	0.23
Expansive Concrete	26700	0.18

These material properties are allocated to the surface of virtual objects because of a surface model and haptic rendering presents the difference among these materials in our system.

4.2 Different features of materials

The user select components(vertices, edges, and faces) while they want to make a shape deformation. At this time, when user selects the shape deformation commands such as move, rotate, and scale, the handle is displayed on the screen. The shape deformation is possible by the drag operation of this handle. The reaction force is generated as a force feedback in the sense of haptic device at the same time. At this time, normal stress acts on vertical deformation(Figure 5), and shear stress acts on shear deformation(Figure 6).
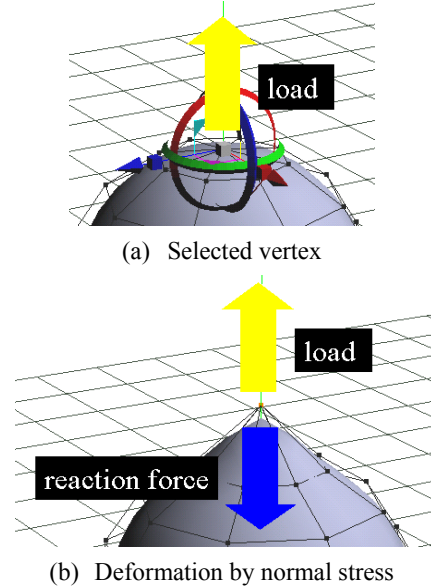

(a) Selected vertex

(b) Deformation by normal stress

Figure 5:Deformation by normal stress with force feedback

(a) Selected faces

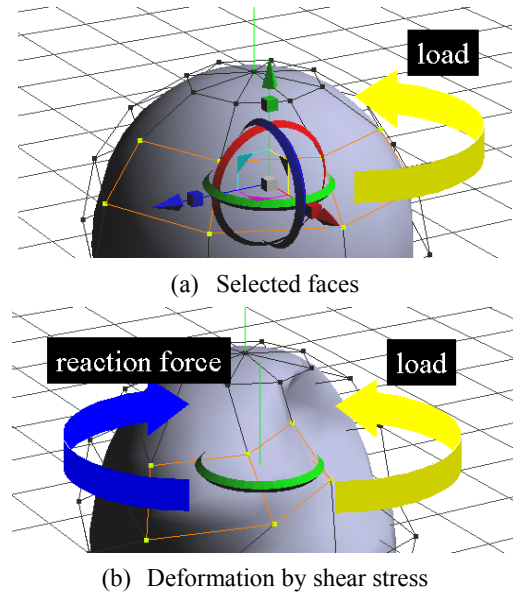

(b) Deformation by shear stress

Figure 6:Deformation by shear stress with force feedback

5. DEFORMATION

5.1 Algorithm

Our system is a surface modeler, so the system excludes the thickness and sectional area of virtual objects. This system contemplates the total of surface area of faces(active polygons) that belongs vertices(active vertices) that belongs to selected components(Figure 7).
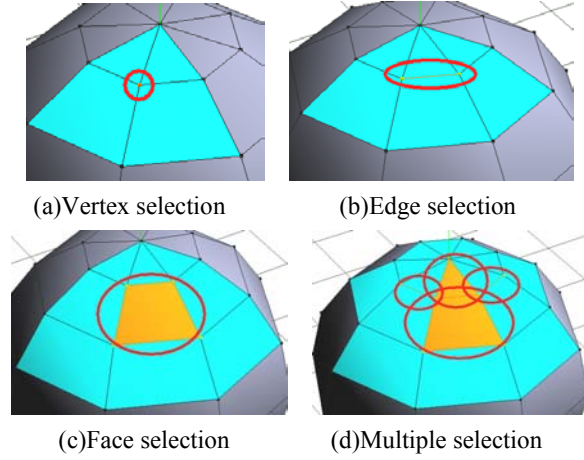

(a)Vertex selection   (b)Edge selection

(c)Face selection   (d)Multiple selection

Figure 7:Selection

The area of orange is selected component and light blue is faces that belongs to active vertices, and the part of orange and light blue are active polygons.

This system presents different features of materials by adding various material properties to the surfaces of virtual models and by feeding back the reaction force which derives from shape distortion. The strengthen of the reaction force to the virtual model at this time is decided according to the following factor.

・ The surface area of active polygons

・ The average of elastic coefficient assigned to active polygons

・ The amount of strain

・ The gain of load

The change rate of length assigns to the amount of strain at the vertical deformation by normal stress, and the rotation angle assigns at the shear deformation by shear stress. A gain of load brings same effects of the real world such as nipper and hammer to reduce the magnitude of the load that human applies. The reaction force is calculated according to the following procedures.

When the component is selected, it searches for active polygon around the component. At this time, the surface area of searched active polygon is calculated.

$$A = \sum_{activePolygon=0}^{n} A_{activePolygon} \qquad (1)$$

Moreover, the sum of the elastic coefficient allocated in active polygon is calculated. After the selection ends, the mean value of the elastic coefficient is calculated.

$$k = \frac{\sum_{activePolygon=0}^{n} k_{activePolygon}}{n} \qquad (2)$$

When the selection ends and shape deformation command of GUI is selected, the handle for the shape deformation is displayed on the screen(Figure 8).
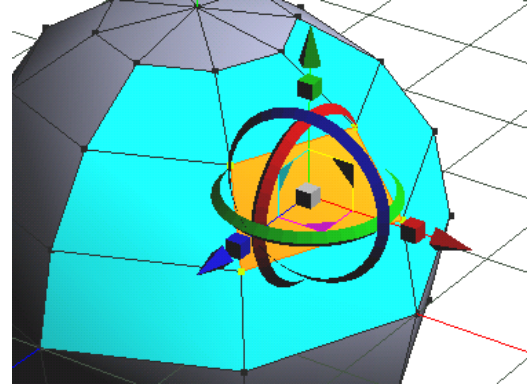

Figure 8:Handle for the shape deformation

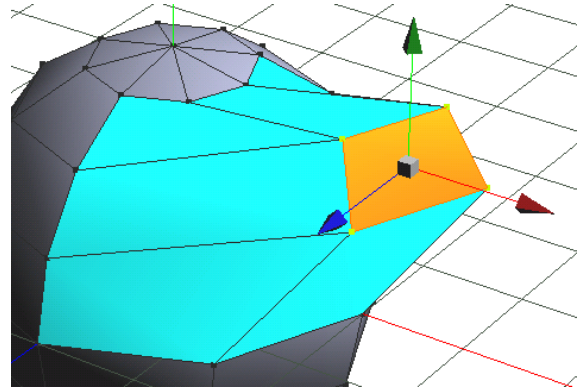Virtual object can be distorted by dealing with this handle in drag operation (Figure 9).

Figure 9:Shape deformation

Reaction force F in handling is calculated by the following formula.

$$F = \frac{Aks}{Gain} \qquad (3)$$

where $A[mm^2]$ is the surface area of active polygons, k is the average of elastic coefficient assigned to active polygons, s is the amount of strain, and *Gain* is gain of the load.

5.2 Haptic elementary deformation

In this modeler, translation, scaling, and rotating are possible as the elementary transformations. The shape deformation is done to the arbitrary element that user selects. It is possible to select it by clicking the virtual objects displayed on the screen. Moreover, it is possible to select it continuously by clicking while pushing the shift key. When the selection ends and shape deformation command of GUI is selected, the handle for the shape deformation is displayed on the screen. Virtual object can be distorted by doing this handle in drag operation. The translations (X, Y, Z, XY, YZ, ZX, and arbitrary direction), the rotations (X, Y, and Z), and the scaling deformations (X, Y, Z, XY, YZ, ZX, and XYZ direction) are possible in our modeler. The reaction force is generated in the shape distortion. A virtual object starts returning to former shape when power to move a haptic device is loosened. The shape distortion stops when drag operation is ended. A virtual object doesn't return from present to former shape because reset is done as for internal force when the drag operation was stopped. In this system, the user can freely decide the axis that user wants to be edited. Therefore, it is also possible to move, to rotate only to X-axis, and to scale.

5.2.1 Translation deformation

The translation of a shape deformation in which the movement of the input device is reflected directly. The shape distortion such as pushing and pulling by moving and gripping the device the center part of handle (white cube) is possible. Moreover, it is possible to translate to the direction of each axis by moving device gripping a conic part in tip of handle (Figure 10). Normal stress acts in this deformation.
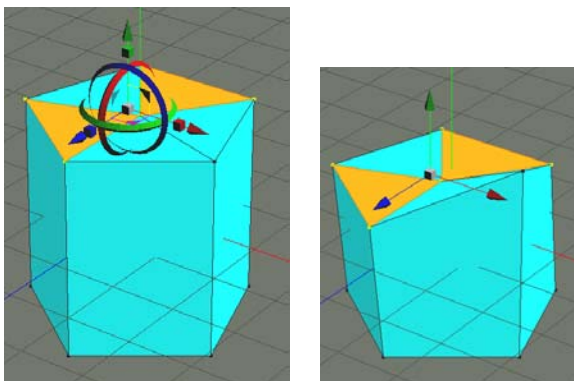

(a) Before Moving   (b) moving XYZ

Figure 10: Translation deformation

5.2.2 Scaling deformation

In scaling deformation, scale-up is possible by inclining to the input device with gripping the handle to the right, and scale-dow is possible by inclining to the input device with gripping the handle to the left. When the device is moved with gripping the center part of handle (white cube), equal ratio of scaling deformation is possible.

Moreover, it is possible to execute the scaling direction of each axis by moving device gripping a cubic part in tip of handle (Figure 11). Normal stress acts in this deformation.
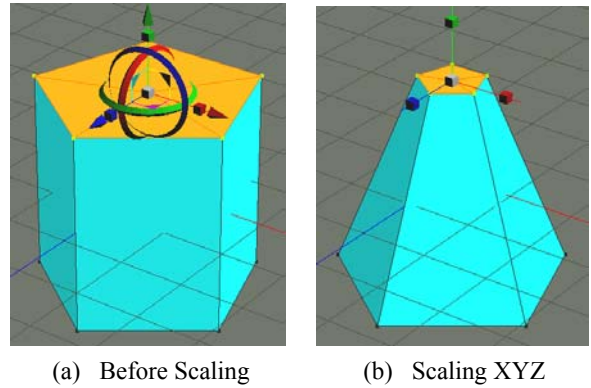

(a) Before Scaling   (b) Scaling XYZ

Figure 11: Scaling deformation

5.2.3 Rotation deformation

The rotation deformation is possible by inclining to the input device with gripping the handle to the right or left,

Moreover, it is possible to execute the rotation direction of each axis by moving device gripping a ring part in tip of handle (Figure 12). Shear stress acts in this deformation.
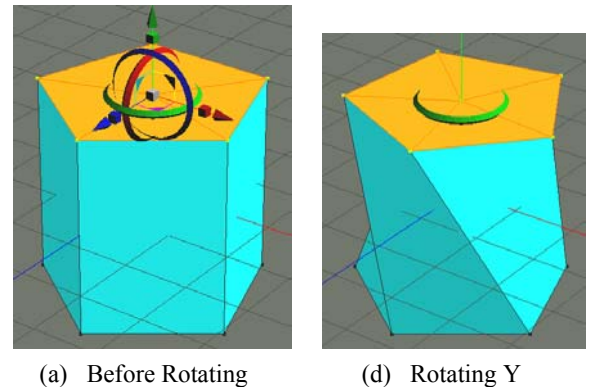

(a) Before Rotating   (d) Rotating Y

Figure 12: Rotation deformation
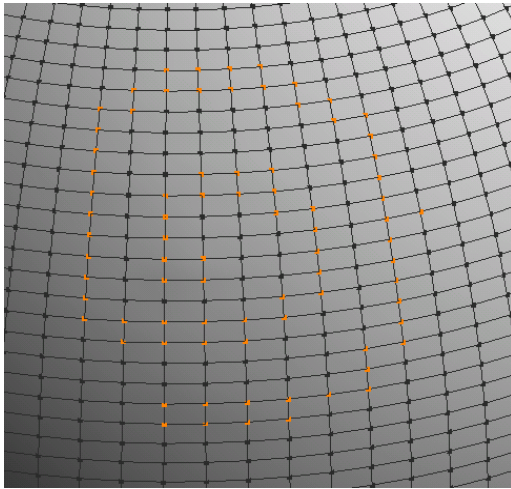
5.3 Haptic Sculpting

This system mounts the brush tool like ZBrush which makes it possible to sculpt with feeling reaction force in each material by PHANTOM that is 3D haptic device. Sculpting by drag operation to arbitrary components of virtual object is possible.
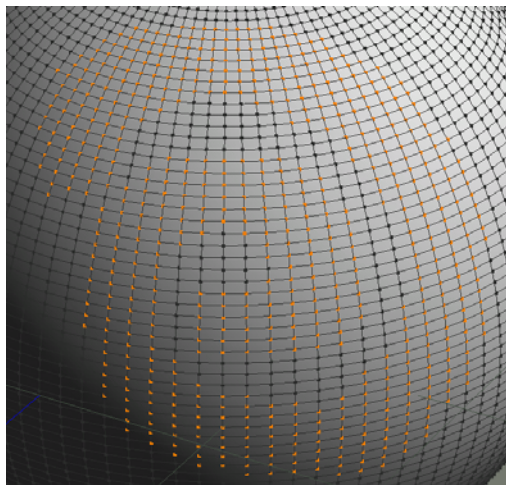
5.3.1 Algorithm

Sculpting algorithm by virtual brush is shown below.

1. The vertices picking is processed to a virtual object within the arbitrary range during drag operation.

2. Sculpting with an arbitrary brush.

Size of virtual brush can be changed by the first processing and the shape of brush is expressed by the second processing. The one that only the first processing was done is shown in Figure13.

(a) Small brush

(b) Large brush

Figure 13: Picking

The part of the orange is the vertices selected in the first processing and can be sculpted in the second processing. This system makes it possible to sculpt with feeling reaction forces in each material by PHANTOM device. Vertex rises when pulling device, and it dents when pushing device. At this time, the ruggedness attaching changes according to the direction where the vertex moves. Figure 14 shows the model sculptured by moving in the direction of normal vertices.
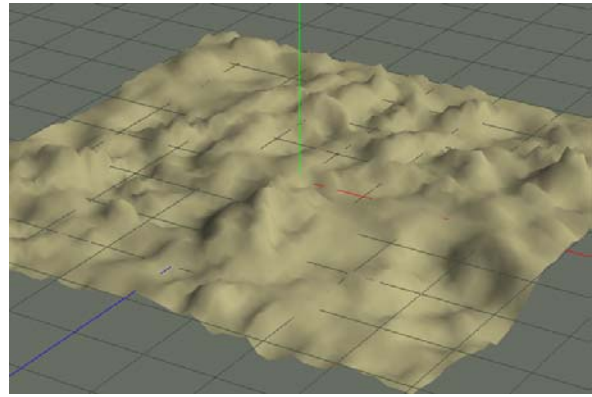

Figure 14: Haptic Sculpting

5.3.2 Brush Shape
Ruggedness effect changes in the form of the brush. It is effective for a special effect to the surface.

For instance, the brush shape when the sine curve is multiplied according to the distance in a center part of effective area in Figure 15 becomes like Figure 16.
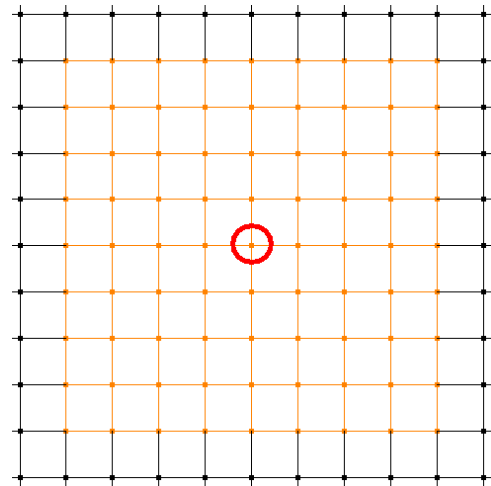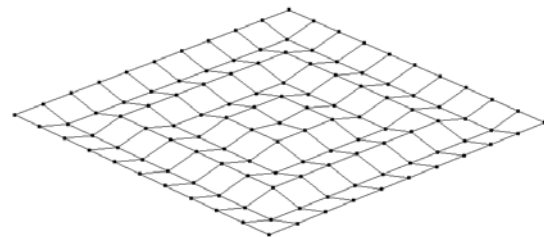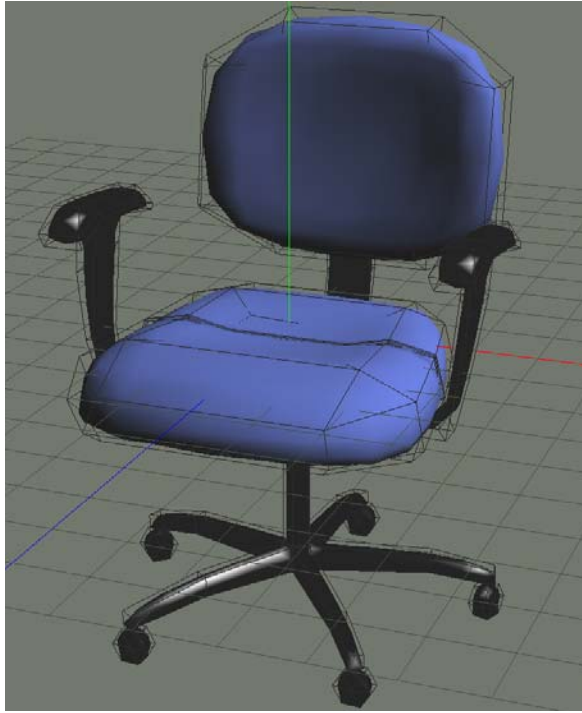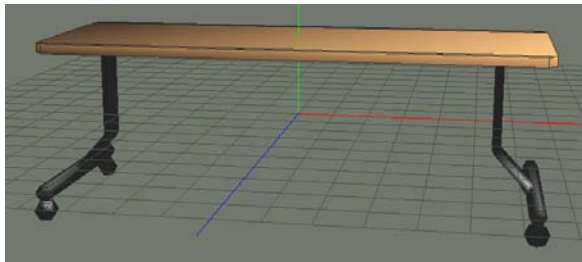

Figure 15: Effective Area

Figure 16: Sine Brush

6. EXAMPLE OF USE

The examples of models created by using this system is shown as follows. The chair and table are produced as an example of interior design (Figure 17). The urethane and steel are used for the materials and wood and steel are used for the table. The expansive concrete and wood are used for the wall of classroom and the glass is used for the windows.
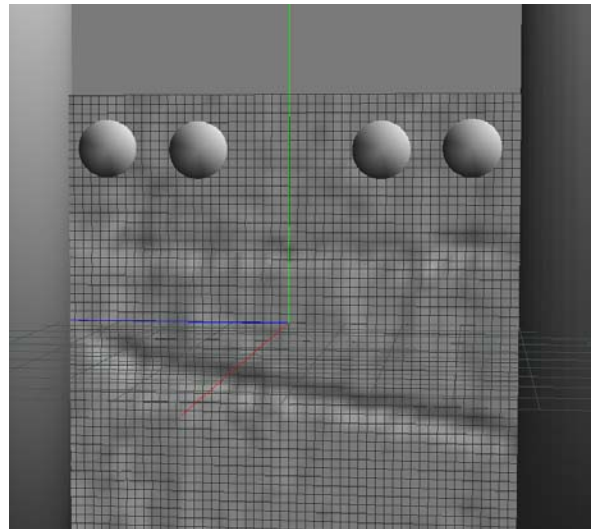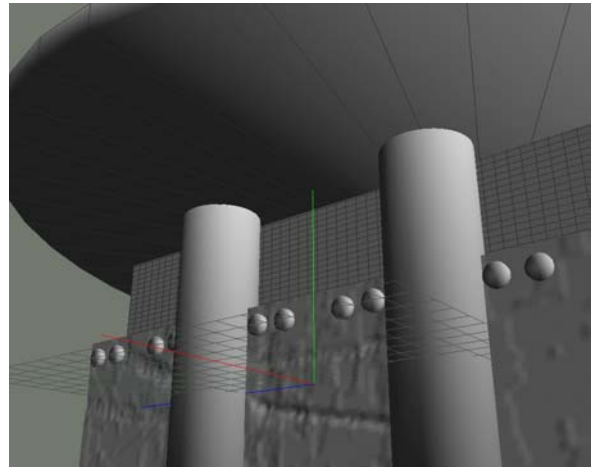

(a) Chair

(b) Table

(c) Classroom

Figure 17: Interior Designs

Figure 18 is an example of construction product design. Expansive concrete is used for the material. Moreover, the sculpture is created by using virtual brush for wall.

(a) Wall Sculpting

(b) Another perspective

Figure 18: Construction product design

7. CONCLUSIONS AND FUTURE WORK

We have presented a free form modeling system based on the strength of materials. We have developed a prototype surface modeling system which enables user to realize more intuitive and realistic modeling in attaching various material properties to virtual objects by means of haptic device with force feedback. We plan to extend the current system with the ability to apply more various material properties. In addition, we will implement the plastic deformation and destruction, and various brush shape. We expect valuable feedback from them that will guide us to improve the framework.

8. REFERENCES

Autodesk, Inc., "3dsMax",

http://usa.autodesk.com/adsk/servlet/index?id=5659302&siteID=123112c

Autodesk, Inc., "Maya",

http://usa.autodesk.com/adsk/servlet/index?id=6871843&siteID=123112

NewTek, Inc., "LIGHTWAVE3D",

http://www.newtek.com/

Avid Technology, Inc., "SOFTIMAGE|XSI",

http://www.softimage.com/

Eovia Corporation., "Hexagon",

http://www.eovia.com/products/hexagon/hexagon.asp

Nevercenter Ltd. Co, "Silo",

http://www.nevercenter.com/

Luxology, LLC, "Modo",

http://www.luxology.com/

Robert McNeel & Associates, "Rhinoceros",

http://www.rhino3d.com/

Takeo Igarashi, Satoshi Matsuoka, And Hidehiko Tanaka(1999). Teddy: A Sketching Interface for 3D Freeform Design, SIGGRAPH 1999, pp.409-416.

Pixologic, Inc., "ZBrush",

http://pixologic.com/

SensAble Technologies, Inc., "PHANTOM",

http://www.sensable.com/products/phantom_ghost/phantom.asp

SensAble Technologies, Inc., "FreeForm",

http://www.sensable.com/products/3ddesign/freeform/FreeForm_Systems.asp

M. Mantyla(1984), "A note on the modeling space of euler operators", Computer Vision, Graphics and Image Processing 26, pp.45-60

D. Zorin And P. Schroder(2000), "Subdivision for Modeling and Animation", In SIGGRAPH 2000 Course Notes, ACM SIGGRAPH