

# Virtual Sculptor: A Feature Preserving Haptic Modeling System

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## ABSTRACT

A real-time interactive modeling system with force-feedback devices and stereo rendering is presented. The proposed system is based on the Extended Marching Cube (EMC) algorithm, which provides sharp feature preservation. Users are also allowed to sculpt an object converted from existing mesh models generated from commercial packages via voxelization. By projecting on a spherical display device, the Virtual Sculptor forms an immersive environment. Furthermore, this fast prototyping tool can also be used as a useful query interface of 3D content retrieval that enables the functionality of modifying more delicate models from the results queried by the rough model.

## Keywords

feature preserving, HCI, Extended Marching Cube algorithm (EMC)

## 1. INTRODUCTION

Although 3D modeling software and related researches have made improvement in recent years, they are mainly focused on precise modeling for CAD and animations. In recent years, a commercial software, *FreeForm<sup>TM</sup>*, proposed by SensAble Technologies is one of the pioneers of related systems with force-feedback devices, to which our system is similar. Moreover, our work is based on our previous work [12] that preserves sharp features by using the EMC algorithm proposed in [9]. With this feature, more accurate models are created even in a relatively low voxel resolution since the EMC algorithm can greatly reduce aliasing. In addition, convenient utilities such as loading a mesh model as either the graver tool or sculpted objects are provided in this system through a voxelization process.

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A force feedback device, the PHANToM is integrated into this system as an extension of our previous work. According to several previous researches presented in [1, 6, 8, 11], users can sculpt, fill material, paint color, and maintain the orientation of sculpted object more intuitively via a 6 DOF (each 3 DOF in translation and rotation) haptic device interface. Force calculation based on the Spring-Damper model provides realistic and quick force reactions [4, 11]. Thus, a bunny model shown in Figure 1 can be more easily created by stuffing and carving operations through the haptic interface.

The other extension of our previous work is to integrate spherical display with stereo rendering. A user can experience the immersion and enjoy the sculpting process while the traditional CRT cannot provide due to the limitation of small viewing angles.

Our system also allows users to load an enclosed mesh model as a sculpted object or as a graver. This feature not only facilitates 3D model reuse by modifying existing models, but also lets users create personal style sculpting by loading a mesh model as the graver. Importing and exporting the created 3D models to the commercial modeling software *Maya<sup>TM</sup>* produced by Alias|wavefront Corp. is available through a plug-in interface. This feature makes our system really useful and provides other options to create models for fast prototyping.

## 2. PREVIOUS WORKS

Several frameworks and application systems for sculpting in a virtual environment have been proposed in recent years. There're two main approaches. The first one is the volumetric approach that is described in several related works [3, 7, 12, 13]. Also, a coarse-to-fine adaptive hierarchical approach is presented in [5] with dynamic subdivision. These pioneer works present a new ideal of modeling in virtual environment. These concepts of volumetric approach are commercialized into practical software production integrated with force feedback device by the FreeForm [1]. The second approach is based on mesh deformations. Some related works are proposed in [6, 8]. They presented a totally different approach by polygonal mesh subdivision, and can also create fine details and sharp features.

For data manipulation, our system is similar to the first concept, the "volumetric approach." The main difference between our work and traditional volumetric-based works is in sharp-feature preserving (see Figure 5, Figure 8.) Users can create impressive 3D models even in relatively low res-

olution. Stereo rendering is also available on a spherical display such as the *VisionStation<sup>TM</sup>* manufactured by Elumens Corps. The key idea of combining this hardware is the presence of the peripheral vision that convinces a user the illusion in virtual environment, although our current model of the Vision Station sometimes can destroy the illusion because of the flickering and the lower intensity of the LCD projector.

### 3. SYSTEM ARCHITECTURE

First we will briefly introduce the pipeline of the haptic system, and then the features of software system and user interfaces. An overview of system architecture is shown in Figure 2.

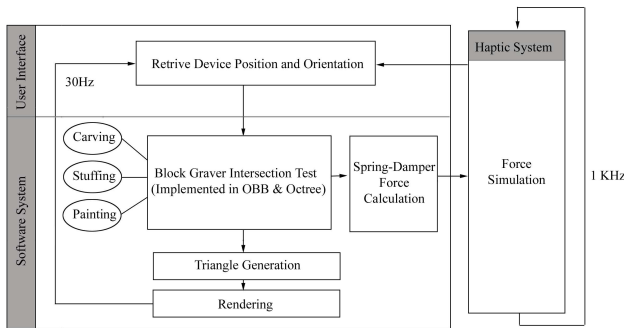


Figure 1: System architecture

#### 3.1 Haptic System

In order to get a stable and smooth force simulation, two different working frequencies are chosen. Real-time interactive system with force feedback device requires a well-designed pipeline that enables the system to run at about 30 fps in rendering and 500Hz to 1KHz in force simulation. For this purpose, we use the two threads approach in which the rendering and force simulation are executed separately. The haptic system pipeline was started as retrieving the position and orientation of PHANToM, which interacts with a user as shown in Figure 2. According to the intersected triangle and the bounding box of a graver, we calculate the force based on the Spring-Damper force model, which will be introduced in section 4.

#### 3.2 Software System

Several basic tools are provided for creating models: the carving tool that cuts material, the filling tool that stuffs material, and a painting tool that paints color on the surface of models.

An "undo" function is also available so that artists can recover a previous operation by a series of carving and stuffing operations. The undo utility is implemented by simply recording the scalar of vertices in the voxel for triangulation and the intersected points on an edge for reconstructing the sharp features. The detailed description of sharp feature preservation is presented in Section 4.2.

Simple graver shapes such as sphere, ellipsoid, cylinder, and box are provided in our system. Users can exploit these tools to create a variety of models. Also, an arbitrary enclosed mesh can be loaded into the system as a graver. This

feature enables a user to create varied and more interesting models from different graver shape styles (as shown in Figure 3).

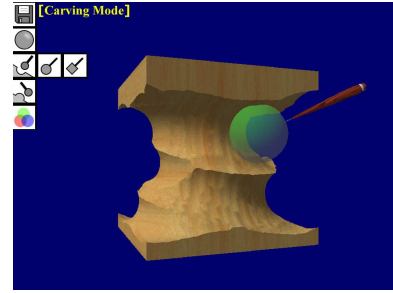


Figure 2: Screen shots from our system

An octree-based and oriented bounding box (OBB) method is applied to a graver for intersection test to speed up the performance in order to run in real-time. Because of the heavy space consumption of voxel storage, we also designed an efficient memory management architecture, which manages the memory usage and data structures. The structure stores common intersection vertices free from redundant memory allocations so that our system can run well in restricted memory space in real-time.

#### 3.3 User Interfaces

Our system allows a user to maintain the position, orientation of a graver and 3D models through the PHANToM, since this user interface is quite convenient. There's also a 2D menu for conveniently changing the graver styles, painting colors, and loading arbitrary graver styles at the edge of the application window.

Stereo rendering implemented in our system further enhances the visual perception of sculpted objects. Our current system enables a user to wear a stereo goggle and work with either a CRT display or the Vision Station, a spherical display device.

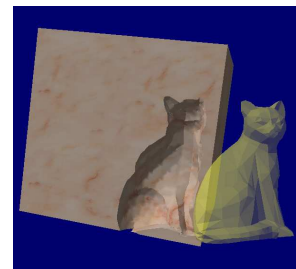


Figure 3: The arbitrary shape graver style, a cat as a graver and the concave hole it cuts.

## 4. DESIGN AND IMPLEMENTATION

#### 4.1 Force Model

The force calculation model we used is based on the Spring-Damper system similar to the work shown in [4, 11], and the force model is represented as

$$F = kx - bv$$

## 4.2 Sharp Feature Reconstruction

Since the surface samples on a globally uniform grid cannot be aligned to the features of the object, a system based on the traditional marching cube algorithm[10] suffers from aliasing at sharp features. Our system solves the problem by recording the feature information and applying the EMC algorithm proposed by Kobbelt, et. al [9].

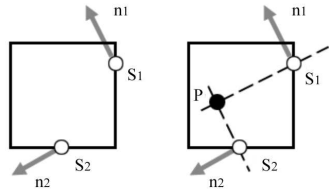


Figure 4: Sharp feature reconstruction

After a simple sharp feature detection rule, we sample the feature point  $p$  (see Figure 6) by solving the following linear system from

$$[\dots n_i \dots]^T p = [\dots n_i^T s_i \dots]$$

where  $s_i$  is the sampling point on surface with its normal  $n_i$ . As shown in Figure 5, we get an impressive result even in a low grid resolution by applying the sharp feature reconstruction algorithm.

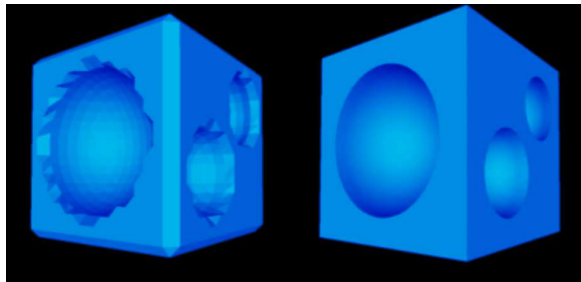


Figure 5: Comparison between results generated by the ordinary marching cube algorithm (Left) and the extended marching cube algorithm (EMC) where sharp features are preserved (Right).

## 4.3 Import a Mesh as a Sculpted Object

In practical 3D modeling, it would be intuitive for artists to import existing models for further modifications and editing. This idea can be achieved easily in our works since we simply transform the mesh model into voxel data via a voxelization process. This facility works well in enclosed 3D models (as shown in Figure 6.a). First, a cat model is loaded into our system via voxelization; then a user creates a new model by adding a tail in just few minutes (see Figure 6.b). This feature makes our work more useful since users can create 3D model by modifying existing models in a short time. Furthermore, the fast-prototyping feature of our system is helpful since a user searches the prototype of subtle models by 3D content retrieval via the rough model enables a modification from more sophisticated model[2].

## 4.4 The Maya Plug-In Interface

A user can import an enclosed mesh model created by Maya into our system via a plug-in interface through the voxelization process. Exporting the model created in our system to Maya is also available. This feature makes our system compatible with a commercial software and explores the possibility of create 3D model in different methods and devices.

## 5. EXPERIMENTS AND RESULTS

The proposed system is performed on a PC with dual-processor Pentium IV 1.5GHz, the PHANToM produced by SensAble Technologies as a haptic device, and an ELSA GLORIA III graphics card for rendering. Our system is implemented in C++ using Direct3D libraries and have an average performance about 30 fps. In order to provide stereo mode for the Vision Station, a ported version on OpenGL GLUT in the rendering part is also implemented.

Several people have tested our system and create 3D models with impressive feature preserving effects (as shown in Figure 8). It takes about a few minutes to half a hour to finish a 3D model which may takes longer time in a commercial modeling software.

## 6. CONCLUSIONS AND FUTURE WORK

In this paper, we present a real-time system for 3D modeling with haptic interface and immersive stereo display. The haptic interface provides the force feedback during sculpting process to simulate haptic perception, which is important for interactive and intuitive model creation. On the other hand, immersive stereo display creates a sensation of accurate geometric depth to facilitate manipulation. Thus, users can intuitively create 3D models by coordinating vision and haptics, and consequently, more subtle sculpting motion makes the preservation of sharp features necessary. Extended Marching Cube algorithm implemented in our system can easily meet the requirement of sharp-feature preservation so that users can create impressive sculptures even with relatively low grid resolution (Eg. 64\*64\*64 grids).

Moreover, existing 3D model can be loaded as an initial work or as a graver shape, and therefore it enables intuitive model modification. Since a plug-in interface between the

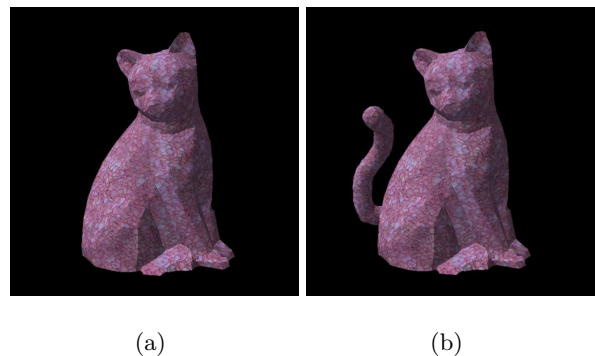
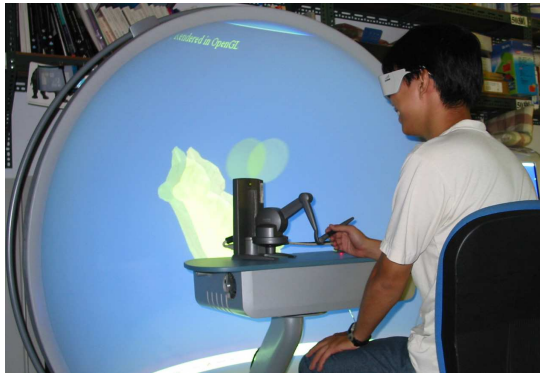


Figure 6: (a) The cat model from a plug-in (b) The original model now has been added a tail using our system.



**Figure 7: Our system works with the Vision Station (a spherical display device) running in stereo mode.**

commercial software Maya and our system are implemented for importing 3D models, it results in an extensive amount of possible initial works from public domain such as on Internet. Our work not only provides artists an alternative modeling method but also an interesting experience of artwork creation in virtual environment.

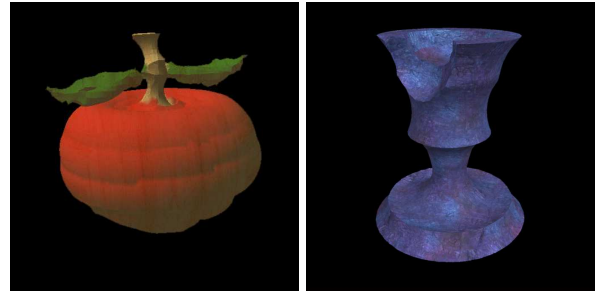
Although the sharp-feature preservation is applied, our current system still suffers from the restricted low resolution. for example, detailed features can not be made when a user wants to build large or sophisticated models. One possible solution of the problem may be integrating the multiresolution approach similar to [5] with sharp feature preserving algorithm, or the composition of several sculpted objects, where each component is created separately. Also, a smoothing tool in our system is required so that a user can smooth the local surface where it is not expected to have sharp corners. Finally, a collaborative version might be implemented in the future since this feature enables multi-user environment and make this work more interesting.

## 7. ACKNOWLEDGEMENTS

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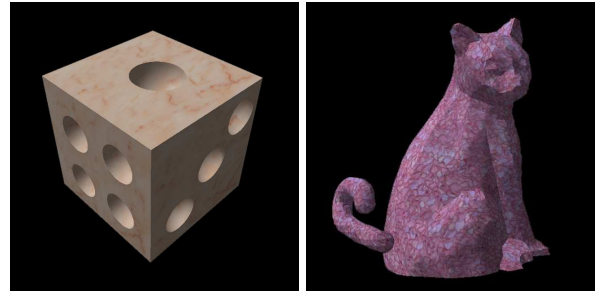
## 8. REFERENCES

- [1] <http://www.sensable.com/freeform>.
- [2] D. Y. Chen. <http://3dsite.dhs.org/~dynamic/>.
- [3] M.-P. C. E. Ferley and J.-D. Gascuel. Practical volumetric sculpting. *the Visual Computer 2000*, 8(16):469–480.
- [4] J. F. P. Brooks, M. Ouhyoung, J. J. Batter, and P. J. Kilpatrick. Project grope— haptic displays for scientific visualization. *SIGGRAPH 1990 Conference Proceedings*, pages 177–185.
- [5] E. Ferley, M.-P. Cani, and Jean-Dominique Gascuel. Resolution adaptive volume sculpting. *Graphical Models (GMOD)*.
- [6] M. Foskey, M. A. Otaduy, and M. C. Lin. Artnova: Touch-enabled 3d model design. *IEEE Virtual Reality 2002*, pages 119–126.
- [7] T. Galyean and J. Hughe. Sculpting: An interactive volumetric modeling techniques. *SIGGRAPH 1991 Conference Proceeding*, pages 267–274.



(a)

(b)



(c)

(d)

**Figure 8: The result models created by our system**

- [8] A. D. Gregory, S. A. Ehmann, and M. C. Lin. intouch: Interactive multiresolution modeling and 3d painting with a haptic interface. *IEEE Virtual Reality 2000*, pages 45–52.
- [9] L. P. Kobbelt, M. Botsch, U. Schwanecke, and H.-P. Seidel. Feature-sensitive surface extraction from volume data. *SIGGRAPH 2001 Conference Proceedings*, pages 57–66.
- [10] W. Lorensen and H. Cline. Marching cubes: A high resolution 3d surface construction algorithm. *SIGGRAPH 1987 Conference Proceedings*, pages 163–169.
- [11] M. Minsky, M. Ouhyoung, M. Steele, F. P. J. Brooks, and M. Behensky. Feeling and seeing: Issues in force display. *Proceedings of 1990 Symposium on Interactive 3D Graphics*, pages 235–243.
- [12] K.-L. Perng, W.-T. Wang, M. Flanagan, and M. Ouhyoung. A real-time 3d virtual sculpting tool based on modified marching cubes. *International Conference on Artificial Reality and Tele-existence, 2001*, pages 64–72.
- [13] S. Wang and A. Kaufman. Volume sculpting. *Proceedings of the 1995 Symposium on Interactive 3D Graphics*, pages 151–156.