Development Scheme of ***JewelSense***: Haptic-based Sculpting Tool for Jewelry Design

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***Abstract* – This paper proposes a framework of development of haptic-based jewelry design named *JewelSense*. In this paper, a prototype of haptic-based sculpting tool for jewelry was developed to be used in model-making stage. A haptic sculpture tool and haptic system are developed in VC++ and rendered by OpenGL. A 3D virtual sculpting tool is modeled and controlled by a haptic device, which is integrated to virtual jewelry model-making 3D environment through the proposed haptic sculpture interface. Haptic technology is applied to jewelry design as virtual art in which designers and goldsmiths are able to create new designs by using virtual sculpting tool. The tool is used in graving jewelry workpieces, which are represented by virtual material such as virtual wax, in virtual jewelry model-making environment. The new shape modeling system allows users to utilize their handicraft skills while working in the virtual environment. The system allows a less constrained, more natural and intuitive interaction with virtual models especially in conceptual design phase. Users are able to physically feel with the designing object while working on the haptic-based sculpting tool. The virtual tool helps for reducing cost and time in product design process. However, this tool is also applicable to other industrial designs.**

Keywords – Computer design support, Haptic shape modeling, Haptic sculpture interface, Jewelry Design, Virtual Sculpting.

1. INTRODUCTION

In a generic jewelry design process, designers sketch their design ideas by hand or by computer-aided design system. Then the sketches are passed to goldsmiths or model-makers to create physical wax or metal models by handicraft. In model-making stage, model-makers need to revise, rework, and modify the physical models to fit with the designers' ideas. This iterative process cause time and material costs. It will be interesting to move this process into digital design and virtual prototyping.

In digital age, virtual art and design plays key roles in new era of product design and development in several industrial sectors. Enterprises are moving from Computer-Aided Design (CAD) system to Computer-Aided Industrial Design (CAID) and from costly physical models to the direct realization of digital models. CAID allows users to physically experiences with the design while working on a computer-based design system such as in [1]. Virtual Reality (VR) technologies offer more realistic and intuitive interaction with three-dimensional (3D) models. Virtual Prototyping is commonly adopting in design and validation phase. Virtual prototypes are typically less expensive, easily configurable and support variants [2]. Therefore they allow for several runs on a single model. Tests are repeatable and results are instantly available for product design view. Virtual Prototyping helps design optimizations, which need several tests or a series of tests. Thus it can reduce testing costs and time and the overall number of physical models used in product design process. However physical prototyping is not completely replaced with Virtual Prototyping.

Haptic technology nowadays offers a revolutionary approach for integrating physical and digital aspects to be exploited in various phases of product development. Haptic devices work as virtual tools allow users to physically experience a sensation of touch and physical properties when they interact or manipulate with virtual objects or materials. Wannarumon [3] had explored the applications of haptic technologies in jewelry design process. She discussed that haptic modeling system enables designers to utilize their manual skills for intuitively interacting such as touch, feel, manipulate and model, with 3D virtual models in the virtual environment, which is similar to natural settings. Furthermore, this method can reduce design iteration and material cost for model-making.

This paper proposes a framework of development of a new shape modeling system, which allows designers and goldsmiths to use their handicraft skills while working in the virtual environment through haptic sculpture interface. It is aimed to assist them to intuitively generate digital design by manipulating haptic device as virtual sculpting tool and to reduce cost and time in product design process.

2. LITERATURE REVIEW

The related works were reviewed in three topics as follows.

2.1 Haptic Technology in New Product Development

Virtual prototyping becomes a popular technology in design and validation in various industries. Virtual prototypes are less expensive compared to physical models. The recent trend aims to use virtual prototyping earlier in conceptual design stage in order to evaluate design concepts, improve product quality, and facilitate designers' activities [2]. Tan [4] explored the use of haptic devices in new product development (NPD) in virtual prototyping. Haptic devices offer a new paradigm for integration of physical and digital modeling. They have been popularly applied to industrial design with a wide range of a simple drawing and/or painting to complex three-dimensional modeling applications.

Haptic technology offer designers to facilitate tactile interaction and manipulation with virtual material and geometry during product modeling.

Haptic interface consist of hardware and software components. For hardware part, an example of commercial haptic device developed by SensAble Technologies is shown in Fig. 1. In this paper, we focus on the software part, which includes haptic rendering and application, which are further described in section 2.3.

The haptic device allows user to touch, feel and manipulate on the virtual object by applying force feedback when the end of the stylus contacts with the virtual object.

FreeForm haptic modelling system combined with PHANToM haptic device is the first commercial CAID system released by SensAble Technologies Ltd. It offers designers using virtual sculpting tools to sculpt and manipulate virtual clay. These activities are similar to sculpting in physical world.

Sener *et al*. [6] evaluated the industrial design and modelling using the FreeForm haptic modelling system and the results indicated that the concept of the system is very promising, particularly in the early stages of design process. Sener *et al*. [7] identified the strengths of FreeForm that contributed to NPD, particularly in idea generation, form exploration, prototyping, and early assessment of ergonomics and production concerns.

Figure 1 An example of commercial haptic device (PHANToM Omni) developed by SensAble Technologies [5]

Figure 2 The use of haptic device in product modeling

Bordegoni and Cugini [8] presented their haptic-based free-form shape modeling system, which is user-friendly, intuitive and effective for supporting designers in the conceptual phase of product design. Chen *et al*. [9] proposed a haptic system, which a haptic device has integrated product development.

A PHANToM haptic device is used in the hardware of the system platform, while the software has been developed for haptic reverse engineering, haptic shape modelling, haptic virtual machining tool path planning, and haptic virtual coordinate measuring machine.

Gao and Gibson [10] presented a haptic sculpting system for B-spline surfaces with virtual shaping tools of implicit surface. Wavelet-based multi-resolution tools are developed to allow users to adjust the resolution of sculpture surfaces; as a result, the deformation scale can be easily controlled. With the use of wavelet technique and the haptic sculpting tools, the proposed system can offer the implementations of sweep editing and three-dimensional (3D) texture.

2.2 Haptic Shape Modeling

Beyond the traditional two-dimensional interfaces such as mouse and keyboard, haptic shape modeling systems provide more intuitive and natural ways in shape modeling. Several researches proposed the applications of haptic devices in shape modeling [2, 6-9, 11].

Chen *et al*. [9] described that in their research shape modeling consists of two operation types: adding and removing material. Adding is the process that an adding tool swept volume of material to existing part. In the opposite, removing is material removal process such as milling, drilling, and cutting. By using haptic shape modeling system, users can create digital models in similar intuitive and direct manner as physical modeling with clay and wax.

However, haptic shape modeling is presently suitable only for conceptual or industrial design rather than engineering design, because in the existing haptic systems the parameter-driven mechanism is insufficient user-friendly [9].

2.3 Haptic Rendering and Tool-Object Interactions

Haptic rendering allows users to feel, touch, and manipulate virtual objects through a haptic interface in simulated environment [12, 13]. Haptic rendering algorithm is developed for computing the correct interaction forces between the haptic interface representation inside the virtual environment and the virtual objects. Haptic rendering algorithms also guarantee that the haptic device correctly renders such forces on the human operators. The haptic interface is virtually represented via an avatar, which a user can interact physically with the virtual objects in the virtual environment. The selection of type of avatar depends on the capabilities of haptic device and simulation applications. The developer may choose volumetric object exchanging forces and positions with user in a 6-dimenional space.

Haptic rendering techniques are reviewed in [13-15]. In general a haptic rendering algorithm [13] consists of three main parts: collision detection, force response and control algorithm, as illustrated in Fig. 3.

There are several types of haptic interaction method used in simulations depending on the applications to render 3D objects. The basic process associated in haptically rendering objects in virtual environments with force feedback device [15] is illustrated in Fig. 4. When user manipulates the probe of haptic device, the new position and orientation of the probe is sensed by the encoders. Collisions between virtual objects and simulated stylus are detected.

Even though the collision detection algorithms developed for computer graphics cannot be directly used in haptic rendering applications, several methods such as space portioning techniques, local search methods, and hierarchical data structures have been developed for fast detection in haptic rendering algorithms [12].

For computer haptics, 3D object representation can be either volume-based or surface-based technique. In volume-based representation, the models are made of voxels, while surface-based models are based on parametric or polygonal modeling. In addition to an existing technique for haptic rendering is based on haptic interaction type: point-based and ray-based.

For point-based haptic interaction method, only the end effector point or haptic interface point (HIP) interacts with virtual objects [12] .

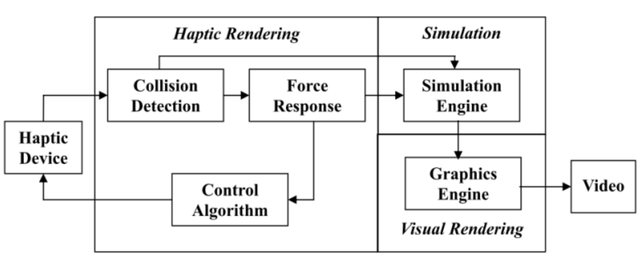

Figure 3 Haptic rendering divided into three parts (modified from [13])

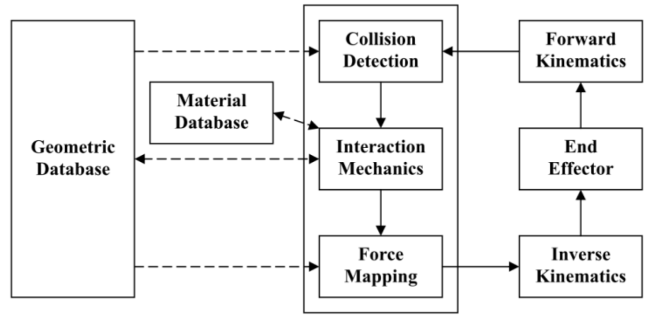

Figure 4 The basic process of haptically rendering objects with force display (modified from [15])

Every time user moves the effector of the haptic device, the collision detection algorithms recognize whether the end of the effector is inside the virtual object.

If it is inside the object, the distance between the current HIP and a surface point will be calculated as the depth of indentation [16, 17]. By using point-based rendering technique, several object representation such as volumetric modeling [18, 19], implicit surfaces [20], NURBS [21] and polyhedrons [17] have been successfully rendered. However, point-based haptic interaction methods are not able to simulate the interactions between tool and object at arbitrary locations of the tool.

A point-based haptic rendering with voxel-based objects was developed by assigning 8 bytes of information to each voxel including material density, density gradient, color, stiffness, and viscosity [18]. If the HIP is recognized as inside a volumetric isosurface of the object, the stiffness and the reaction forces are computed using the scalar density field at the HIP through a set of linear transformations. The surface normal computed using central difference approximation is defined by the gradient of the density field at the HIP. Another point-based haptic rendering equipped with the PHANToM haptic interface device was developed for rendering simple objects such as sphere, cube, and cylinder [22]. The depth of indentation is considered as the distance between HIP and the nearest surface point. Space partitioning techniques are used for dividing the object into sub-spaces. When the HIP goes through a region shared by multiple sub-spaces, the direction of the resultant force vector is calculated by superposition of surface normals. There are several problems found in this method [15]. Firstly, it is difficult to divide an object into sub-spaces. Secondly, the superposition of force vectors cannot work well for complex and thin objects. A more sophisticated point-based method was developed for haptically rendering polygonal surfaces [17]. New location of surface point is calculated when user operates the probe of haptic interface using a constrained optimization technique. The distance between object and HIP is minimized. Although HIP goes inside object, the object point always stays on the surface of the object.

For ray-based haptic interaction method, the effector or probe of the haptic device is modeled as a line segment and its orientations is considered, as well as the collisions between tool and object are detected between the line segment and the objects [12]. The collision detection algorithms give a set of intersection points between the line and the surface of the object. This method allows user to simultaneously interact multiple objects and both force and torque interactions can be simulated, which are not possible with the point-based method. Furthermore, ray-based method can recognize 3D objects faster than point-based method [23]. Therefore, ray-based rendering method can approximate the interactions between long tools and objects, which is desirable in medical application [24]. In the case of the shape geometry of the effector is complex and is difficult to model using a set of line segments, the simulation of 6 DOF object-object interactions should be considered [12].

A ray-based haptic rendering method was developed for rendering 3D objects in virtual environments [25]. The probe of the haptic stylus is modeled as a line segment. Its position and orientation are provided by the encoder signals. When user manipulates the stylus, the simulated stylus is updated to the coordinates as the actual one. The collisions between the virtual object and the simulated stylus are detected. The reaction force is estimated by using the linear spring law and reflected to the user via the user interface.

Reaction force (F) of both point-based and ray-based method is typically calculated using the linear spring law [15],

$$F = kx \qquad \text{(Eq.1)}$$

where k is object's stiffness and x is indentation depth. In the case of frictionless interactions, the reaction force (F) is normal to polygonal face that the stylus collides with. In the case of rigid objects, k is set as high limited by the contact instabilities of the device.

3. System Overview

The proposed design system named ***JewelSense*** is based on haptic technology and interaction modalities, which simulate physical tools and manipulations performed by goldsmiths in physical world, to support modeling jewelry objects. The followings describe the system architecture, haptic tool for virtual wax sculpting, and shape modeling operations.

3.1 System Architecture

The system architecture shown in Fig. 5 provides the overall architecture of the haptic-based sculpting system, which consists of haptic rendering and graphic rendering.

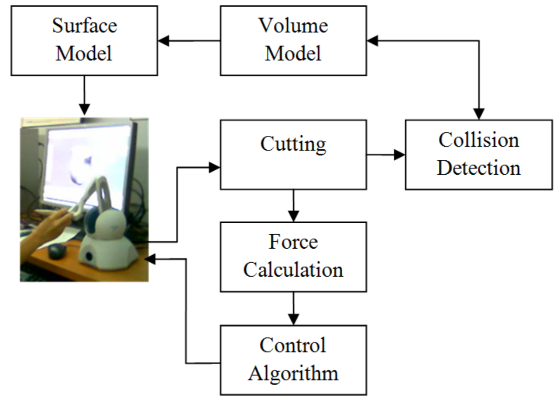

Figure 5 The system architecture of haptic modeling system ***JewelSense***

Figure 6 Virtual carving wax model (left) and virtual carving tool (right)

3.2 Model Representation

In this system, volumetric-based representation method is used for modeling virtual carving tools and virtual wax models, to represent volume data for visual and haptic interaction. In volumetric representation, a volume is represented as a 3D voxels. Each voxel specifies a set of scalar properties at a discrete grid location. To provide the continuity of each property, the interpolation function is used for generating a continuous scalar filed for each property.

The two parts simulated on the screen are the carving tool and the wax model. To generate the force interactions between tool and object, some physical properties are required. The scalar values of density and material classification and shading properties of materials of the stylus tip (hardened steel) and of hard wax are used for generating density gradients and partial shading results for each voxel. As well as mechanical (haptic) properties are including stiffness and viscosity of both materials.

3.3 Haptic Carving Tool

A PHANToM Omni haptic device (shown in Fig 1.) is used as haptic input/output device in this system. The PHANToM Omni device provides six degree-of-freedom (DOF) positional sensing for input and feedback. It can work as a small robot arm, which is equipped with computer controlled DC motors. A stylus is connected to the device, and users can use it as a virtual tool, as shown in Fig.7.

3.4 Haptic Rendering

The software is written in VC++ and rendered by OpenGL. Haptic interaction type used in this paper is point-based technique. Haptic rendering algorithm is shown in Fig.8.

3.5 Collision Detection

The collision detection algorithm detects collision between virtual wax model and virtual carving tool in the virtual environment and provides information of position, contact area, and collisions have occurred.

4. RESULTS AND DISCUSSIONS

The proposed haptic sculpting system ***JewelSense*** discussed in this paper was implemented on Intel Core 2 Duo with a 2.93 GHz E7500 processor and 2 GB of RAM. A PHANToM haptic interface was connected to the system via an IEEE 1394 port firewire. The software is written in VC++ and rendered by OpenGL with point-based haptic interaction.

The interaction forces are approximated from two principal requirements. The interaction forces are calculated with the update rate of 1 KHz, while visual frequency is at 30 Hz and they should be consistent with the volumetric object rendering within the interactive system.

Figure 7 The simulated carving tool handled by using the stylus of PHANToM haptic device

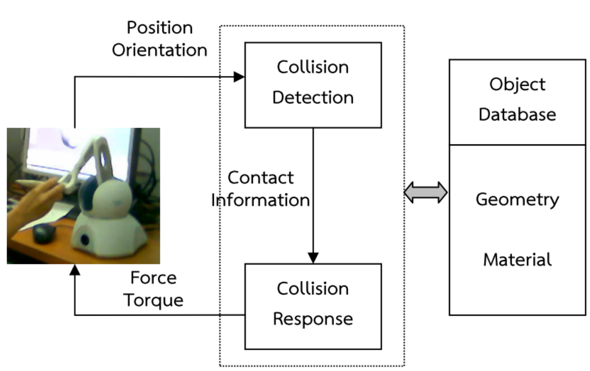

Figure 8 Haptic rendering algorithm in haptic loop of ***JewelSense*** Haptic modeling system (developed from [12])

The major requirements of the haptic-based design system are constant haptic refresh rate, fast force feedback, fast, incremental rendering, fast data modification and consistent haptic and volume rendering.

The proposed haptic system is a point-based haptic rendering with voxel-based objects. Haptic interaction type used in this paper is point-based technique; therefore the force approximation is applied onto a point contact in order to achieve the requirement of interaction speed. The system allows users for manipulations of volumetric object. An example of the haptic carving in jewelry ring design is shown in Fig. 9.

A design task for designing jewelry ring was organized for five participants in order to observe the difficulties that users obtain whilst interacting with the haptic carving system. Five participants consist of two industrial design students, two industrial engineering students, and one jewelry designer. Two industrial design students have experience on hand sketching in jewelry design in average level. Two industrial engineering students are familiar in modeling jewelry objects using computer-aided design system, while the jewelry designer is familiar in hand sketching. Nevertheless, they all never have experience on haptic device.

All participants satisfied and got pleasure from the haptic device. They found that the device is easy and intuitive to use. Although, when they firstly started using it, they required a short time to be familiar with the device and the system.

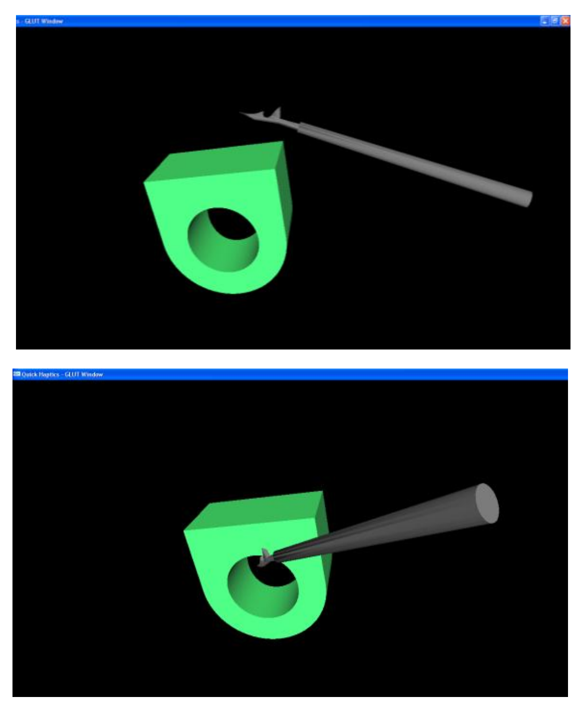

Figure 9 Examples of haptic carving in jewelry ring design

The advantages of working with the digital system are that users are able to go backward or redo when they do some mistakes, they can work anywhere not only in laboratory or studio or on goldsmith workbench and they can reduce material costs because of working with digital (virtual) wax on the screen.

Comparing the proposed haptic sculpture system to the available commercial systems, the designing object and virtual sculpting or carving tool are more realistic in terms of shapes. Moreover, the system can be adjusted and modified according to user's requirement.

However, the proposed haptic sculpture system still needs to be improved its user-system interaction interface, as well as to be added various digital craving/sculpting tools and various digital wax models.

5. CONCLUSIONS

This paper proposes a new haptic-based sculpting tool for jewelry modeling named ***J**ewel**S**ense*. It is developed by using voxels to create volumetric modeling and rendering of virtual tool and designing object and using point-based technique for haptic interaction. The more realistic sculpting tools and the wax models created are more suitable to be used in jewelry prototyping comparing to the available systems.

With the ***J**ewel**S**ense*-haptic sculpting system, designers and goldsmiths can use a stylus of PHANToM haptic device to control a virtual or simulated tool to manipulate a digital wax on the screen. They are able to touch, feel and deform a CAD model by pushing, cutting, and graving its surfaces in a 3D environment. Haptic-based design tool has great potential to become a significant interface for product design applications.

6. ACKNOWLEDGMENT

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