A Touch-based Collaboration over the Network

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Abstract

We present a collaboration system incorporating haptic interface which allows us to share the virtual environment and haptic interactions with people at different locations. Haptic interface provides physical sensation and an intuitive and effective tool in collaboration along with visual and auditory information. In our system, each user performs painting and sculpting operations directly on the 3D model via a haptic device and simultaneously sends haptic interactions to the remote user to maintain the same environment. Network model of our system is peer-to-peer without central server. We introduce shared information and simple strategies to keep data consistency among participants.

Key words: Collaboration system, Haptic interface, Haptic collaboration, Multimodal human interface.

1. Introduction

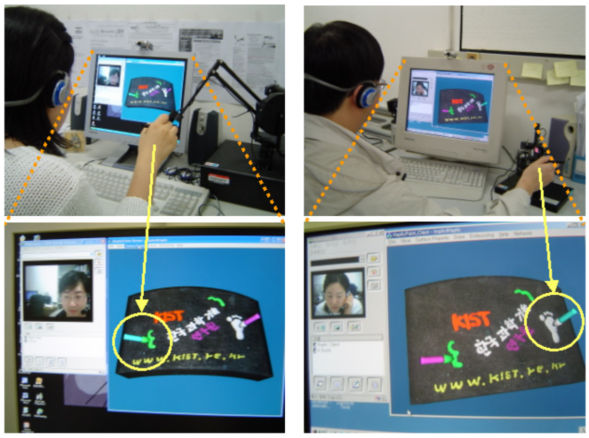
Collaboration system enables people in remote places to communicate and cooperate with providing interfaces for sharing environment.

Video and audio conferencing systems are most common in collaboration. They provide face-to-face meeting among remote users over the network. One of them is *NetMeeing* [1] included in MicroSoft Windows which is an internet conferencing tool with text chatting, white board, file transfer as well as point-to-point audio and video conferencing.

Virtual Reality (VR) collaboration systems allow us to share the virtual environment and interactions in 3D space. These systems provide more natural interface with richer information than vedio/audio conferencing. *Virtual director* [2] has been developed to make a VR collaborative session with up to four people at remote locations. This system provide audio conferencing, gestual motion capture, and void control of navigation, editing, and recording.

Haptic interface allows a user to touch, explore, paint, and manipulate virtual 3D models in a natural way just as one interacts with the physical environment through the sense of touch. We have developed haptic rendering techniques based on the hybrid surface representation which is a combination of geometric model and volumetric model [3]. We have also developed haptic painting and sculpting systems which allow us to edit directly on the 3D model [4].

In this paper, we propose a touch-based collaboration which integrates haptic interface into traditional VR collaboration systems. The haptic sensation not only increases a sense of presence but also provides an intuitive and effective tool in collaboration. In our collaboration system, remote users cooperate to edit the 3D model by performing painting and sculpting by sharing haptic interactions.



(a) *(b)*

Figure 1: A collaborative painting session between two users at remote locations, (a) and (b)

Figure 1 shows a collaborative session using our system. Two participants at remote places share a virtual environment and cooperate to paint the virtual environment using PHANToM haptic devices from SensAble [5].

We proceed with a discussion on our haptic techniques in section 2. Section 3 describes haptic paint and sculpting techniques. Touch-based collaboration is described in section 4. We conclude and suggest future work in section 5.

2 Haptic Model

In this section, we describe our haptic rendering algorithm based on a hybrid surface representation, haptic painting, and sculpting techniques. Geometric model is used for visual display and volumetric implicit surface for haptic rendering. We enhanced the previous works [3, 4] in our lab for better haptic sensation.

2.1 Data representation

Our algorithm is based on a hybrid surface representation a combination of geometric (B-rep) and implicit (V-rep) surface representations for a given 3D object, which takes advantage of both surface representations. For the visual display, the geometric model can effectively represent the 3D model compared to volume rendering. Meanwhile, the implicit surface representation has many properties that address the limitations of current geometric haptic algorithms and introduce new haptic and visual effects.

In the volumetric representation, only potential values close to the implicit surface are involved in the computation (see Figure 2). The potential values inside the close neighborhood of the surface range from -1 to 1 according to the proximity to the closet point on the surface. The values inside the surface are negative and positive outside. The values out of this narrow band are nothing to do with the surface modeling and haptic rendering. Therefore, to reduce the memory requirement, we use an octree-based data structure, avoiding the representation of empty portions of the space.

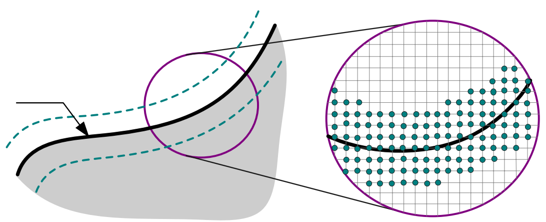


Figure 2. Volumetric representation

2.2 Force model

Based on an implicit surface representation, collision detection becomes trivial due to the inside/outside property. If the potential value at the virtual tool position is less than 0 (inside the surface), a collision is detected. The force direction is computed by interpolating the gradients of 8 cell points around the virtual tool. The interpolation function leads the system to avoid the force discontinuity.

In order to determine the amount of force, the system finds the virtual contact point (VCP) on a surface which is the intersection point between the surface and a ray along the computed force direction from the tool tip point. The amount of force is proportional to the distance between the VCP and the tool tip. Once the VCP is determined, a spring-damper model is used for force control to make the system stable as follows:

$$F = k * (p_c - p_t) + b * V \qquad (1)$$

where $\boldsymbol{F}$ is the force vector, $\boldsymbol{p_c}$ and $\boldsymbol{p_t}$ are coordinates and the VCP and tool tip in 3D space respectively, $\boldsymbol{V}$ is the difference in velocities of the VCP and tool tip, k is stiffness constant, and b is viscosity constant. Spring stiffness has a reasonably high value and viscosity is to prevent oscillations.

Another advantage of our haptic model is independent of the model complexity since the algorithm is implemented based on implicit surface rather than geometric data.

3 Haptic Painting and Sculpting

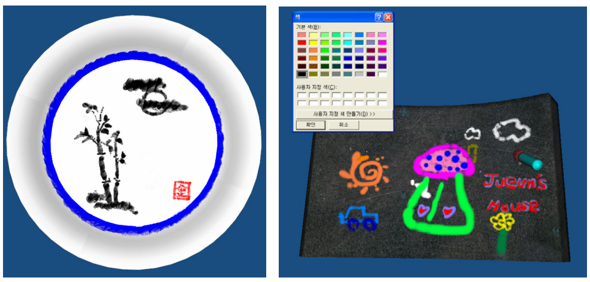
This section describes haptic painting and sculpting techniques in our system.

3.1 Haptic painting

Haptic painting allows the user to paint directly on the desired area on 3D model using a haptic device.

When the user touches the surface to be painted, the system first finds 3D triangles within the brush volume of which the center is the VCP on the surface using the volumetric representation. To find the seed face to start the rasterization, the system performs an intersection test between a line segment from the tool tip position to the VCP and faces around the VCP. The system then walks through all faces within the 3D brush volume starting from the seed face until no new face is found (this process is known as a flood-fill algorithm).

However, this flood-fill algorithm might not find all triangles within the brush volume on the overlapped area of multiple objects or the surface with high frequency. For the volume-fill, the system checks all faces indicated by grid points within the brush volume. If it finds a new face within the brush volume, this face is used as a new seed face to perform another flood-fill (called a volume-fill algorithm). The system then rasterizes corresponding 2D triangles in the texture map, one by one, using a standard scan conversion similar to *inTouch* [6].



(a) Pottery decoration *(b) Painting by a casual user*

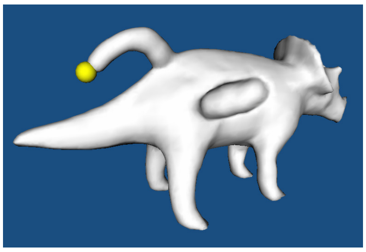
Figure 3. Examples created by our haptic painting

Each texel's color is determined by a function of the brush size, brush color, fall-off rate, background color, and distance to the center of the brush volume during the triangle rasterization. The amount of applied force or a user-specified size determines the size of the brush volume. Figures 3 show examples created by our haptic painting technique.

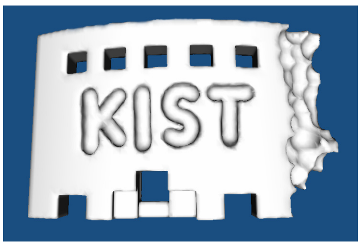
3.2 Volume-based haptic sculpting

We developed a virtual sculpting system based a volumetric implicit surface as an alternative to existing digital sculpting implementations. While adding or carving operation, the volumetric model is converted into the geometric model every graphical frame for the visual rendering.

In order to represent sharp edges with a smaller number of triangles, we employ the adaptive polygonization method suggested by Velho [7]. This adaptive method consists of two steps. In the initial polygonization step, uniform space decomposition is used to create the initial mesh that serves as the basis for adaptive refinement. In the second step, for adaptive polygonization, the mesh is refined adaptively according to the surface curvature until the desired accuracy is achieved and then projected onto the implicit surface. The resulting mesh effectively represents sharp edges with a smaller number of triangles and does not introduce cracks. The volumetric implicit surface and generated mesh are saved into separate octree-based data structures to locally manage both data.



(a) Triceratops model being editing



(b) A model with KIST logo

Figure 4. Examples created by our haptic painting and sculpting.

Haptic sculpting has another limitation. The system typically could not update the physical model at a rate sufficient for haptic rendering (at least 1 KHz). To bridge this performance gap, we introduce an intermediate implicit surface. The intermediate surface is animated from the old surface toward the target surface in haptic process. The speed of animation depends on the force by the user and local material stiffness. Examples created by our haptic sculpting system are shown in Figure 4.

4 Touch-based Collaboration

In this section, we describe touch-based collaboration over the Internet.

4.1 Communication architecture

Network model of our system is peer-to-peer in which one peer directly communicates with another without central server introducing further transmission delay between server and clients. Each peer has a duplicate of virtual environment independently and sends changes to the remote partner to keep data consistency. Virtual environment is updated based on all interactions by both local (solid line) and remote users (dotted line in Figure 5).

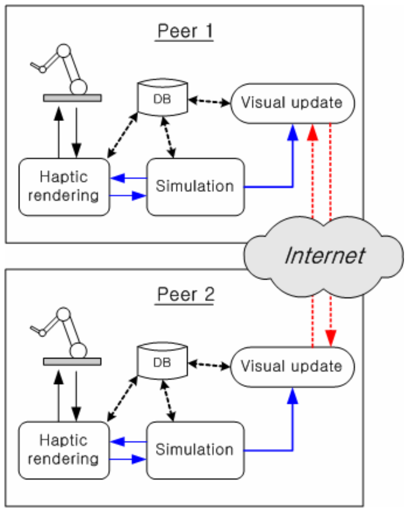


Figure 5. Peer-to-peer network model

4.2 Messages for sharing environment

The messages to be exchanged among participants include the position and orientation of haptic cursor and interactions to trigger visual changes of virtual environment while painting and sculpting via haptic devices. There are two types of messages for touch-based interactions.

The message for collaborative haptic painting contains the center of brush volume, the size and color of brush tool. For collaborative haptic sculpting, sculpting type (adding or carving), contact position in 3D space, tool size, and amount of being sculpted. The amount is proportional to the total force applied by the user until the next visual frame. The size of packet is small enough to send message without splitting in a given network bandwidth.

Updating the virtual environment is implemented by 4 steps each visual frame (see Figure 6). First, the system makes a delay to keep the fixed visual update rate of all systems in a collaborative session. Next, data of virtual environment is updated based on interactions by the local user. In the painting mode, texture information around the haptic cursor is updated and in case of sculpting mode, the volumetric data is modified to represent the shape being sculpted. In the same way, the third step updates the virtual environment one more time to simulate changes by the remote partner. Finally, the system draws the modified virtual environment.

4.3 Data consistency

Data consistency is a requirement for collaboration over the network. We use TCP/IP protocol providing reliable data transmission and packet ordering in peer-to-peer architecture.

In order to guarantee consistency of virtual environments, data transfer delay is fixed by the maximum delay time. In case of LAN, fixed delay time is 10 ms. In addition, virtual world should be updated at a fixed frequency (30Hz). For instance, if one system update two times faster than the other, the slow system may lose half of changes created by the fast one. Finally, data transfer delay time should be lower than visual display delay time. Otherwise, some of changes could not send to the remote users resulting in inconsistency of virtual environment.

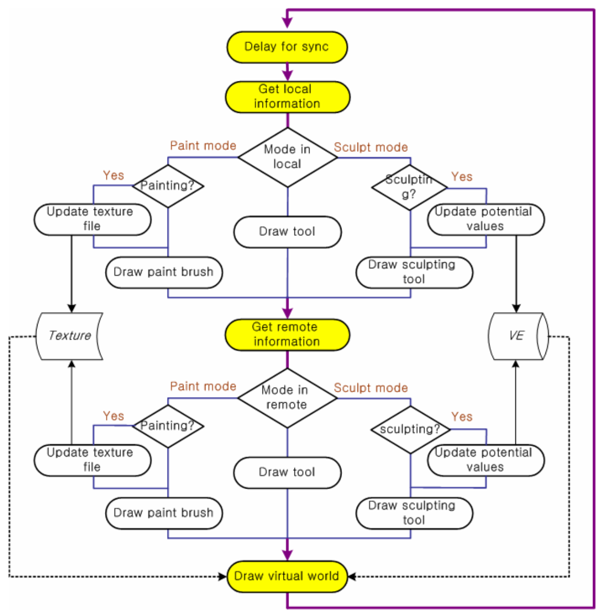


Figure 6. Visual update process.

4.4 Multi-modal workbench

We developed the Multi-Modal Workbench (MMW) which incorporates a stereo-visual display (viewed in a mirror), a PHANToM haptic device, a 6 DOF position device and an auditory display. Thomas et. al, first suggested a similar system for near-field virtual environment system [8].

The system is designed to register three sensory modalities such as visual, haptic and auditory sensation. The user views the images on a mirror reflecting the monitor mounted on the MMW (see Figure 7). This configuration allows the user to touch virtual objects without blocking the screen. In order to align the visual and haptic spaces, it requires elaborative calibrations. We will use the multi-model workbench for an immersive touch-based collaboration.

(a) Multi-modal Workbench system

(b) The user views images on the mirror

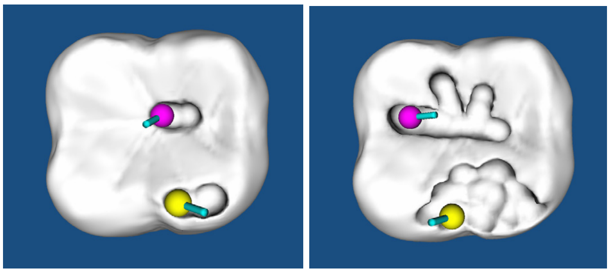
Figure 7. Multi-modal Workbench

5 Conclusion and Future work

We introduced a touch-based collaboration which supports collaborative painting and sculpting via tactual sensation between remote users. Incorporating haptic interface provides an intuitive and effective tool and physical experience. Basic strategies for data consistency have been described. Figure 8 shows a collaborative sculpting session to manipulate a 3D model.

Current system has some limitations. All systems involving in collaboration are located on the same LAN with low delay time, less than 10ms. So, we have to consider the network situation with high delay time on wide area network. In addition, server-client model will be employed to handle concurrent access rather than peer-to-peer.

We plan to apply our touch-based collaboration to various applications such as medical training simulators and collaborative digital art.



(a) *(b)*

Figure 8. A 3D object edited in collaborative sculpting session. One user with the yellow tool and the other with the purple tool. (a) 3D model being sculpted (b) applying more sculpting operations

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