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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

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Non-Realistic Haptic Feedback for Virtual Sculpture

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Thème 3 —Interaction homme-machine,
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Abstract: The sense of feeling can effectively be used to enforce virtual artistic activities like virtual sculpting or modeling. In this paper, we describe how a virtual sculpture system has been extended with haptical feedback. In practice, we use the scalar field defining the implicit surface being modeled to efficiently compute several type of force feedback. We present a method for combining these forces differently depending whether the user is just touching his artwork or editing it by adding virtual matter. This technique enforces the interactivity of the task and leads to an enhanced non-tactorealistic feedback that increases the usability of the sculpture tool. The well-known problem of stability of the haptic feedback is also addressed in the particular case of implicit surface, in a new, simple and efficient manner.

Key-words: virtual sculpture, haptic interaction, non-realistic haptic feedback

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Rendu haptique non-réaliste
pour la sculpture virtuelle

Résumé : L'utilisation du sens du toucher permet de faciliter les activités artistiques virtuelles comme la sculpture ou le modelage virtuel. Dans ce rapport, nous décrivons comment un système de sculpture virtuelle a été augmenté grâce au rendu haptique. En pratique, nous utilisons le champs de potentiel scalaire définissant la surface implicite modelée pour calculer différents types de forces. Nous présentons une méthode qui permet de combiner ces forces de manières différentes suivant que l'artiste ne fait que toucher sa création ou qu'il la modifie en ajoutant de la matière virtuelle. Cette technique renforce l'interactivité de la tâche et crée un rendu haptique non-réaliste qui améliore l'utilisabilité de l'outil de sculpture. Le problème classique de la stabilité du rendu haptique est résolu dans le cas particulier des surfaces implicites d'une manière nouvelle, simple et efficace.

Mots-clés : sculpture virtuelle, interaction haptique, rendu haptique non-réaliste

1 Introduction

Like every artistic process, virtual sculpture (see figure 1 for example), requires a strong interaction between the artist and his artwork. Feeling the material being modeled enforces the metaphor of sculpting and the immersion of the user, making the creative activity easier. The need for haptic feedback is even stronger when the user visualizes his 3D sculpture on a standard screen: without force feedback, correctly positioning an editing tool with respect to the sculpture is difficult, since it may require changing the viewpoint several times to check the tool's position.

Fortunately, the incorporation of force feedback in a virtual sculpture system does not need to follow the same strict constraints of a physical or surgical simulator. Indeed, there is no strong need for tactile realism in virtual sculpture, since the aim is rather to enhance the artist's ability to be creative. This freedom allows the use of new techniques, offering a more expressive haptic rendering, similar to the way non-photo-realistic rendering [11] enhances certain aspects of the models being displayed.

This paper proposes an effective solution to the incorporation of expressive haptic feedback in a volumetric sculpting system, together with a simple solution for reducing the instability problems during the interaction. As our results show, our new haptic rendering improves interactivity and immersion, thus making the sculpting system far easier to use.

Figure 1: An artwork modeled with a virtual sculpture application. This sculpture was achieved without haptic feedback within 4 hours. (Illustration extracted from [6])

1.1 Previous works

Interactive modeling based on discrete scalar field representation introduced by Galyean and Hughes [8] is interesting because it doesn't focus the user on the mathematical representation of the shape being modeled. Recent developments of this kind of representation [13, 7] showed that it's a good way to model 3D free form shapes. We chose to extend such a system [6] because the potential it uses can easily be interpreted as a density of virtual matter.

Adding force feedback to virtual sculpting is a natural evolution to improve the immersion of the user. The implicit surface formalism is well suited to compute force feedback simulating the objects as showed Avila [3, 2]. On other systems, as the one based on B-splines models described in [5], computing force feedback at the interactive rate of $1kHz$ is really a challenge.

The stabilization of haptic feedback is a classical issue, but general answers as in [1] lead to complex theoritical models. The simplicity of our representation and the fact we are not trying to simulate precisely the reality permitted the development of a simple method addressing this issue.

1.2 Overview

Section 2 quickly reviews the virtual sculpting system we are using and the way classical volumetric force feedback calculations can be adapted to this framework. Section 3 introduces a non-realistic, expressive haptic feedback that switches between different modes of haptic rendering depending on how the artist is interacting with the sculpture. Section 4 gives an original and simple solution to the stabilization of feedback forces. Section 5 concludes and presents future work.

2 Background

We present here the modeling system we have extended and how the definition of the implicit surfaces it creates can be used to compute force feedback. More extensive presentation of the virtual sculpture software can be found in [6].

2.1 Implicit surface modeling

The surface is modeled in this system using an isosurface of a volumetric scalar field function. This field is sampled over a cubic grid (see figure 2). Only the cubes containing a non-zero potential value are stored by the system. An ovoid tool can be used to add or remove "matter" to the sculpture by adding or subtracting its contribution to the scalar field. To expand or delete a part of the sculpture the tool is applied near the surface, which is difficult to locate even with stereo rendering.

The field can be seen as the density of matter defining the sculpture. When the local value is greater than a threshold, the point is inside the surface and when it's smaller, the point is outside.

(a) (b) (c)

Figure 2: The field function sampled over a grid showing: (a) cubes containing a positive value - (b) cubes intersecting the isosurface - (c) the corresponding isosurface.

A classical *marching-cube* algorithm can be used to find the isosurface and compute its triangulation that is rendered with dedicated hardware and a graphical library like OpenGL (see figure 2c). To have a realistic rendering of the surface, normals to the faces are computed using the gradient of the scalar field which is, by nature, decreasing from the inside of the isosurface to the outside.

2.2 Computing haptic forces

The haptic rendering is done with a *Phantom desktop* device, which is a 6DOF articulated arm able to render 3D force feedback [12]. Figure 3 shows the use of the *Phantom desktop* to model a character. The forces presented, because of their simplicity, can be computed at about $1kHz$ on a dual $195MHz$ R10000 processor SGI Onyx2, eliminating the need for a distributed architecture, which is often used to achieve interactive haptic feedback.

The advantage of having a volumetric sampling of the scalar field function and defining the surface and of its gradient needed for the rendering is that interesting local information is available to compute force feedback. As Avila [3, 2] showed, there is no need to make complex computations to calculate plausible forces. Our forces express in a simple way pseudo-physical properties: volumetric viscosity and surfacic contact.

Figure 3: A user modeling a character with the virtual sculpture sofware and a *Phantom desktop* device.

Viscosity

Equation 1 shows how a friction force can be computed. This force tends to resist the movement proportionally to the material density and to the speed of the movement.

$$\vec{f_v} = -\alpha f_{v0} \frac{V}{V_0} \dot{\vec{p}} \tag{1}$$

Constants in equation 1 are: α, a positive constant dimensionally equivalent to the inverse of a speed; f_{v0}, the friction intensity on the surface; V_0, the value of the potential defining the isosurface. $\dot{\vec{p}}$ is the speed at the point $\vec{p}$. V is the value of the scalar field function at the same point and $\vec{f_v}$ is the resulting volumetric viscosity force for this point and speed.

This force grows with the density of matter and the speed of the tool and is directed in the opposite direction of the movement. This reaction makes the user feel the volumetric property of his artwork by the resistance it opposes to the movement but it doesn't give any clue about the surface.

Contact

Equation 2 shows how the surface can be expressed in term of force feedback. This force is normal to the surface and grows rapidly when the tool enters the isosurface. The intensity of the force is clamped to ensure the safety of the simulation as shown in figure 4.

$$\vec{f_c} = -f_{c_0} \frac{gr\vec{ad}(V)}{\|gr\vec{ad}(V)\|} \left(\frac{V}{V_0}\right)^e \tag{2}$$

This force is locally equivalent to a spring model with stiffness e if we consider the field function V as a distance to the isosurface. This haptic feedback gives the user the ability to touch his artwork by feeling contact with the isosurface.

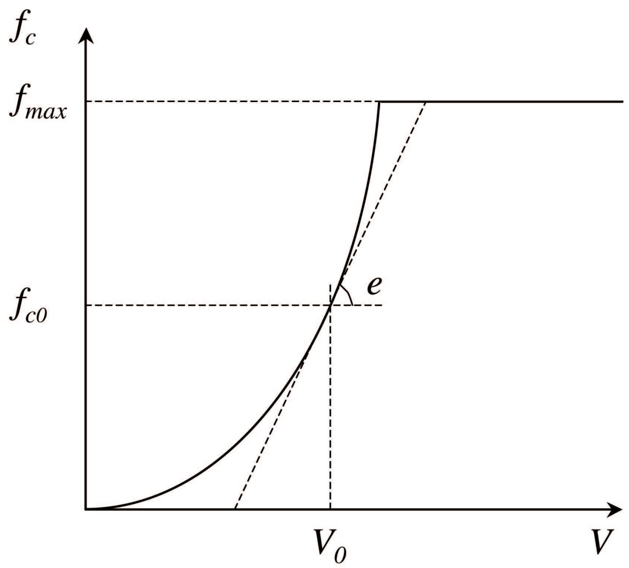

Figure 4: Intensity of the contact force and the local spring approximation on the isosurface.

3 Modes for the force feedback

The forces computed are not a physical simulation of a reality but they rely on psychophysical properties we want the sculpture to mimic.

With those two forces expressing volumetric and surfacic properties of the sculpture, it's possible to give the user a good feeling of his work [10]. We extend this technique by using different combinations of the forces according to the user's intentions.

3.1 Forces combination

We found that the surfacic force is very useful when positioning the tool on the sculpture but can be disturbing when the user edits his work. If the tool can't enter inside the sculpture, carving an existing model is difficult. By attenuating the surfacic force when the user modifies his sculpture and enforcing the volumetric rendering, we reinforce the feeling of manipulating matter, not only a surface.

Thus, two combinations of the forces are used depending on the interaction mode of the user. Equation 3 is used when the user is passive and equation 4 when he's applying a tool. When the user is passive, the surfacic force dominates and when he's active, the volumetric force takes over, which can be expressed by: $\alpha_p > \beta_p$ and $\alpha_a < \beta_a$. The variation of each relative contribution is expressed by: $\alpha_p > \alpha_a$ and $\beta_p < \beta_a$.

$$\vec{f} \quad = \quad \alpha_p \vec{f_c} + \beta_p \vec{f_v} \tag{3}$$

$$or \quad \alpha_a \vec{f_c} + \beta_a \vec{f_v} \tag{4}$$

The transition between the parameters is done smoothly to avoid discontinuities in the resulting force by using the equation 5 where p varies continuously from 0 when the user is passive, to 1 after he has started to apply the tool, and from 1 to 0 for the opposite transition.

$$\vec{f} = (\alpha_p + p(\alpha_a - \alpha_p))\vec{f_c} + (\beta_p + p(\beta_a - \beta_p))\vec{f_v} \tag{5}$$

3.2 Non-tactorealistic feedback

Using forces computed with a psychophysical model rather a physical one and changing the haptic representation of the object being manipulated according to user actions provides an expressive force feedback. This rendering adapts the simulation of the reality to the action of the artist, providing different feedback for the same object. This variability makes it non-realistic but enhances the interactive experience.

We achieve the goal of reinforcing the impact and the usability of the simulation by making it less realistic, in the same way non-photorealistic picture does for visual rendering. That is our notion of non-tactorealistic feedback.

4 Stabilization of the haptic feedback

If the update of the force at $1kHz$ rate is not reached, this is a potential source of vibration in the system. This requirement is not an issue with our system because of the simplicity of the forces. However, a haptic simulation can't be stable in every condition because of the user being involved in the loop [9].

The original solution presented here is a particular case of virtual coupling introduced in [4] without using complex linear circuit theory as in [1].

4.1 Origin of the vibrations

By its definition resulting of a gradient, the surfacic force tends to repulse the tool in an area where the magnitude of the force is smaller. The lag introduced by the user in its reaction makes him resist to a strong force when the tool is already outside the active area. Then, he doesn't meet a resistance and reenters the repulsing area. The repetition of this sequence causes the unexpected vibrations.

Filtering the force to make it vary smoothly is not a good solution because it doesn't guarantee that the position, resulting of the concomitant action of the user and the haptic feedback, will never jerk. Our solution is to filter the position coming from the device and to use this filtered position that can't vibrate, to compute the force feedback. As a side effect, this force is naturally smooth.

4.2 Filtered position

To avoid vibration, a damped position is computed using a low-pass filter that cuts the high spatial frequencies of the real position of the device. This filter is just an exponential damping having a time constant adapted to the vibration we want to cut. Equation 6 gives the definition of the damped position $\vec{p_d}$ in function of the real one $\vec{p_r}$, τ being the time constant of the filter.

$$\begin{array}{rcl} \vec{\delta p} & = & \vec{p_r} - \vec{p_d}(t-1) \\ \vec{p_d}(t) & \leftarrow & \vec{p_d}(t-1) + \tau\vec{\delta p} \end{array} \tag{6}$$

Using this damped position eliminates the vibrations well. However, cutting the high frequencies of the movement introduce a lag that is noticeable in high amplitude movements. We can then use the fact that those movements, even at high speed, are not vibration but express the user's intention to really move to another area. The vibrations are then characterized by high frequencies and low amplitude.

So we compute (see equation 7) a confidence γ varying between 0 and 1 in the damped position depending on the distance between the real position and the damped one. If the two positions are close, meaning there is a potential vibration of low amplitude or that the tool doesn't move, the confidence in the damped position is 1; if the position is far away, the confidence tends to 0. The distant constant λ characterizes the amplitude of movement we want to cut.

$$\gamma = \frac{1}{\|\vec{\delta p}\|/\lambda + 1} \tag{7}$$

A filtered position resulting from a combination of the real and damped one is then computed using this confidence. Equation 8 shows this filtered position $\vec{p_f}$ as a linear combination of $\vec{p_r}$ and $\vec{p_d}$.

$$\vec{p_f} = \gamma \vec{p_d} + (1-\gamma)\vec{p_r} \tag{8}$$

The continuous variation between the real and damped position makes it unnoticeable to the user and the surfacic force resulting can't be discontinuous.

4.3 Spatial coherence

An interesting property of the filtered position can be deduced from the precedent relations. Equation 8 directly implies equation 9; from 6 we can deduce 10 and then 11 can be deduced from 7.

Finally, we can deduce that the distance between the filtered position and the real one $\|\vec{p_f} - \vec{p_r}\|$ is always smaller than λ, the distance characterizing the confidence factor (equation 12).

$$\begin{aligned}
\|\vec{p_f} - \vec{p_r}\| &= \gamma\, \|\vec{p_d} - \vec{p_r}\| && (9)\\
&= \gamma\, \|\vec{\delta p}\| && (10)\\
&= \frac{\|\vec{\delta p}\|}{\|\vec{\delta p}\|/\lambda + 1} && (11)\\
&\leq \lambda && (12)
\end{aligned}$$

This property ensures a spatial coherence between the real position and the filtered one used to display the tool and to compute the forces by guaranteeing they will never be distant from more than λ. This distance being of the same order than the magnitude of the vibrations, it's rather small and the user can't even notice the offset between the two. The guarantee expressed above ensures a good immersion of the user needed to make possible artistic work.

Figure 5: This sculpture was achieved by one of the authors with haptic feedback within less than 1 hour.

5 Conclusion and future work

Using the non-tactorealistic feedback together with the filtered position for its computing greatly improves the usability of the virtual sculpture software. While we have not done formal evaluation, initial tests of this system seem promising. Figure 5 shows 3 views of a sculpture modeled within less than 1 hour with the same software than the one used to produce figure 1 augmented with the haptic feedback. Details have been easier to model and the time loss to locate the tools against the sculture by rotating the view around the model has disappeared.

An interesting direction for the future work is to compute a force that is not only a function of the position of the center of the tool but that takes into account the tool's geometry. A resulting force can be integrated in its intersection with the sculpture. Performance issues made this approach unusable in the virtual sculpture system we used but this system has recently been extended with a multiresolution sampling of the field function [7]. Choosing the appropriate level of details depending on the tool's size to compute a resulting force in fixed time should make this approach possible.

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