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Manipulating Virtual Hair and Textiles

Manipulation von virtuellen Haaren und Textilien

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Abstract: The actions of modelling and manipulating virtual objects in three-dimensional environments are required for a number of applications in the virtual prototyping process for industrial production as well as in the movie and entertainment business. The research and development of interactive systems enabling such operations focus on reproducing the visual appearance, dynamic behaviour and contact response of the simulated objects. This paper presents two application examples of interactive manipulation frameworks which have been respectively designed for the interaction with virtual hair and virtual textiles.

1 Introduction

The 3D representation of animated objects is largely exploited in many industries since over two decades. The touch-based interaction with such objects for modelling purposes, on the other hand, is an increasingly active research area with huge application potential. However, simulating the contact interactions enabling to model complex deformable objects in virtual reality environments and reproducing the associated haptic sensations are challenging tasks. Their computationally intensive character requires defining an appropriate trade-off between the allowed simulation accuracy and the requested performance. Time-critical tasks must be individually computed at the desired speed and efficiently synchronized in order to enable a physically plausible interaction experience. Hence, applications enabling haptics-based manipulation require a tailored and computationally efficient design. In this paper we discuss two such systems for the interaction with hair and textiles.

2 State of the Art

While the computation of interaction forces arising during rigid object contact has been extensively discussed over the past decade and is now well understood, there are still many open challenges linked to the manipulation of deformable objects. Hair and textiles represent prominent examples of complex deformable objects displaying nonlinear and anisotropic dynamic and haptic behaviour.

The accurate handling of mutual hair-tool interactions requires accounting for hair-tool, hair-head and hair-hair collisions with ideally approx. 150,000 hair strands animated in hard real-time in a physically based way. Hence, all attempts proposing haptic interaction facilities with hair have been urged to strongly simplify these aspects. Pioneering approaches such as the interactive virtual hair dressing rooms and salons (cf. MAGNENAT-THALMANN et al. 2006; WARD et al. 2006) aim at the simplified reproduction of the actions performed in a real hairdressing context and achieved very interesting results. They allow a variety of interactions such as hair cutting, grasping, wetting/spraying and drying – but not brushing/combing for hairstyle purposes. Repulsive forces for haptic feedback are derived from the penetration depth of tool-hair contact, considering the hair as a volume. Later approaches have defined tool-hair interactions at strand level and introduced the handling of torque interactions (cf. BONANNI et al. 2009) using individual hair strand mechanics (cf. BERTAILS et al. 2006). Such systems however display a limited scalability and difficulties in maintaining contacting hair strands at explicit positions. Promising answers to these problems are given by the use of explicit approaches such as the discrete elastic rods model (cf. BERGOU et al. 2008) extended to handle hair specifics (cf. KMOCH et al. 2009).

Simulation of textiles has caught the interest of scientists for more than 20 years now. While some methods developed in that course just aim at generating visually pleasing results (e.g. WEIL 1986), others are based on physical principles. The latter approach employs numerical integration to solve the differential equation that combines the physical laws, describing acceleration of masses, and the material's constitutive equation, relating deformation to forces. Significant contributions to this group have been made by (TERZOPOULOS et al. 1987; BARAFF et al. 1998).

However, restriction in the available hardware in the early years, research at first concentrated on simulating the movement of cloth in a non-real-time fashion. With the advent of faster computers, it has become possible to perform the necessary calculations for small models in real-time and recently with increased physical accuracy (cf. VOLINO et. al 2005). This is a prerequisite to be able to create interactive simulations for haptic interaction.

3 Manipulating Virtual Hair

The cumbersome modelling process employed by most commercial software makes the creation of complex 3D objects – for example, the hairstyles of virtual characters – a long and tedious task lasting up to several hours. The optimization and speed-up of the hairstyling process can therefore significantly support 3D artists during their creative work. In this context, we make a step towards enhancing digital hairstyling with force-feedback. Our interaction framework aims at reproducing the contact forces arising during a virtual hair combing process in a simple way. We satisfy the real-time constraints through several optimizations, but at the same time we aim at physical plausibility, and base our approach on selected physical constants identified from the relevant literature in the hair science research domain. With respect to the full range of the physical properties of hair fibres, we identify a limited set of particularly relevant properties which we take into account for the computation of the hair dynamics and the haptic rendering. This simplification allows achieving real-time performance while maintaining the possibility to simulate different hair types on the basis of varying physical parameters.

Besides the hair mass and geometry, for the hair dynamics we model the major axis bending stiffness and centreline twisting rigidity. We neglect tensile hair properties since we assume that natural interaction with real hair will not elicit forces able to cause hair elongation. We also neglect the bending over the fibre's minor axis because the hair strands' elliptical cross section makes fibres naturally bend over their cross section's major axis only (cf. SWIFT 1995).

For the haptics parameters we rely on the concept of hair handle, which defines how far specific mechanical properties of hair fibres affect haptic sensations such as softness, smoothness, combing ease or manageability during handling interactions. Cosmetic research studies analysing hair handle have ranked the bending stiffness and the frictional properties of the hair fibre surface among the main haptically relevant physical properties (cf. WORTMANN et al. 2006).

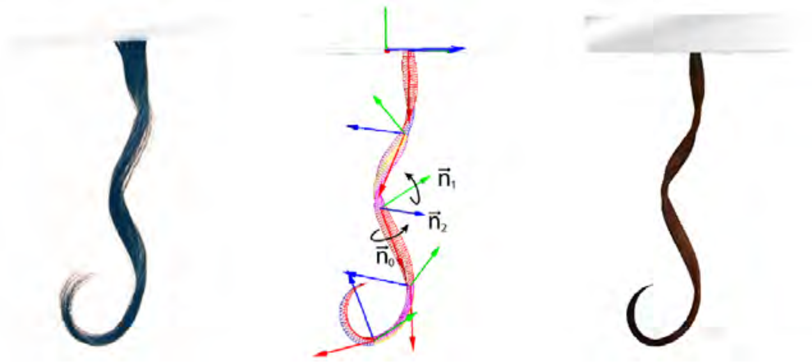

Figure 1: *A wisp of real hair (left) simulated as a Simplified Super-Helix (centre) whose five segments can twist around the centreline (n_0) or bend over the major axis (n_1). We render the 3D strand with a texture from the real sample (right).*

3.1 Simulation

We compute the dynamics of individual strands on the basis of the Cosserat Theory of Elastic Rods and taking into account the physical properties described in the previous Section. We represent hair strands as unshearable, inextensible Cosserat rods parameterized by the arc length. Each strand is composed by a centreline and an orthonormal material frame giving the orientation of the cross-section for each point on the centreline. We lean on the Super Helix model (cf. BERTAILS et al. 2006) and appropriately simplify its degrees of freedom. Reconstructing the centreline amounts to the sequenced attachment of helicoidal segments of piecewise constant twisting and major-axis-bending values (cf. Fig. 1). The computation of the hair dynamics consists in solving the equations of motion expressed in Lagrangian mechanics. The resulting system of equations relates the kinetic, potential and dissipation energies acting on the strand to the centreline mass influenced by gravity, wind, and external force and torque sensed from haptic interaction (cf. BONANNI et al. 2009).

3.2 Haptic Interaction

We compute the hair dynamics and the haptic interaction within separate threads running at different rates. Within the haptic thread, the interaction force is computed from the motion exerted by the user through the haptic device and the physical properties of the contacting hair strands considering the previously described haptically relevant parameters: bending modulus and surface friction. In addition to the translational component of the interaction we consider a torque component, which is especially required for tool-based interaction purposes. This contribution has a minimal effect on the system's computational load, but it greatly enhances the manipulation power of the user, who can now induce arbitrary curvature changes along the relevant axis according to the movement applied through the virtual tool. Force and torque are accumulated over the course of one visual simulation step. The update between the two threads eventually propagates the accumulated interaction dynamics to the simulated strands.

3.3 System Results

Our interaction scenario displays a brush-shaped tool (user-controlled through the haptic device) which allows to engage in interaction with hair strands (cf. Fig. 2).

Figure 2: *Interaction framework (left) and a tool-hair interaction scene (right)*

The overall behaviour of virtual hair strands adequately corresponds to their real counterpart. Slight differences in detailed movements arise as a natural consequence of the necessary approximations of the simulation model. The evaluation of the force feedback perceived during haptic interaction is somewhat difficult. Users quickly gained confidence with the system after a short adaptation phase, but some of them also reported difficulties in the perception of a clear feedback because of the low forces involved in the tasks. Successive subjective evaluation ratings involving an augmented feedback (by 10 % and 25 %) showed a high standard deviation and could not provide statistically relevant insights about an ideal feedback scaling. The experiment performed without force feedback, however, was consistently rated less convincing than all variants returning interaction forces, confirming the positive influence of force rendering during object manipulation (cf. MORRIS et al. 2007).

4 Manipulating Virtual Textiles

The challenge in the manipulation of virtual textile is to create a visuo-haptic system that is able to form a link between numerical simulations computing physically correct deformations while having a high rate update in the contact force. Moreover, as the system has to allow the assessment of various mechanical parameters of textiles, it is necessary to consider the interaction with two fingers at minimum for grasping, i.e. sensing elasticity by stretching and roughness by rubbing over the fabric. Especially the latter action requires tactile devices providing small scale force components at the finger tips resembling the vibratory signals generated in the movement of the finger over the fabric's fine surface structure. Thus, an integrated system was designed to convey the aforementioned touch stimuli.

However, such interaction scenario (cf. Fig. 3, left) poses the problem of complex contact geometries during the touch as a fabric itself is mostly very flexible and tends to fold around the fingers. The separation in visual and haptic simulation was necessary in order to fulfil the demands of haptics and real-time simulation. This multi-rate approach (cf. BÖTTCHER et al. 2010) consists of a textile model (cf. VOLINO et. al 2005) which simulates the nonlinear large-scale mechanics of the whole cloth surface at visual rate and another computing the local deformation of textile and interaction forces at the contact area with high update rates of 1 kHz.

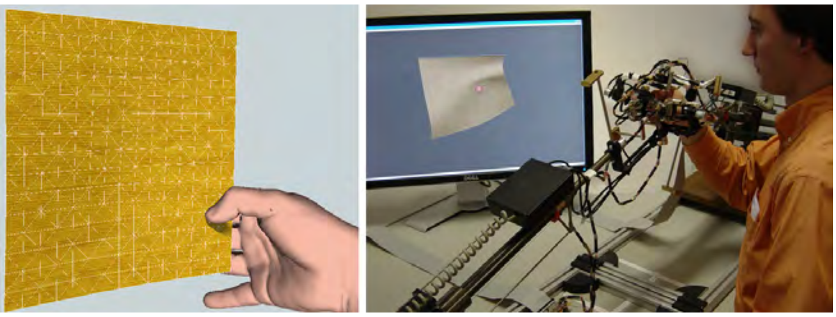

Figure 3: *Interaction Scenario (left) and user operating the system (right)*

4.1 Simulation

With the textile considered as a continuous and deformable body, its motion governed by the laws of continuum mechanics. However, the common way in mechanical engineering to apply FE-methods in order to find the exact motion is unsuitable for real-time animation. Instead, a particle system representation is used to simplify the computations of the non-linear differential equations involved in the physical laws. Despite the simplification to a particle system, the simulation is still able to represent the anisotropic mechanical response of textiles.

Applying special formulations (cf. VOLINO et al. 2005) reduces the computational effort in the textile simulation significantly to achieve very high update rates. More importantly, it also connects the force computation with the real material response measured in weft, warp and shear to reach higher physical realism.

The mechanical response of a textiles caused by deformations is obtained with the KES-F System (cf. KAWABATA 1980). To measure the mechanical resistance, e.g. against stretching, the machine (Fig. 4, left) elongates the piece of fabric constantly and measures the opposing force. The resulting values of the force are approximated by a spline curve for each deformation mode, i.e. weft, warp and shear. The curve is then (see Fig. 4, right) evaluated within the simulation to compute the complete force response.

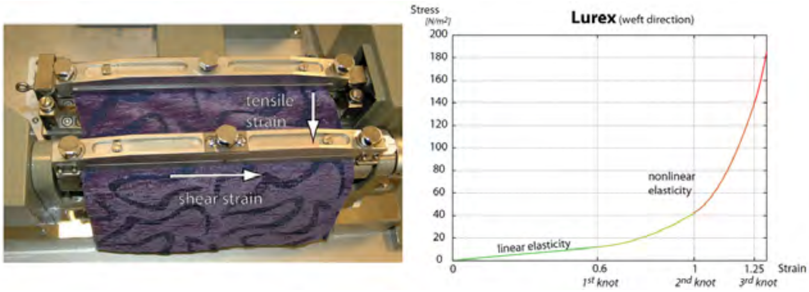

Figure 4: *Machine of KES-F system deforming fabric (left) and example of force response returning a nonlinear plot (right)*

4.2 Haptic Interaction

In the haptic rendering, representing the force at the user fingers touching the textile, the contact model is fed by the mechanics of the local simulation. Therefore, the model needs to construct the contact formulation within the small time frame as well. Unfortunately, the standard methods differ in their mechanical formulation not only yielding incompatible results with respect to the used particle model for the textile but also requiring finding the equilibrium in several iterations. The latter made them yet unusable for the constantly changing configuration of a highly deformable and very dynamic textile. As consequence, the standard mechanical models (e.g. by Signorini) used to model the contact were not yet suited for the real-time context. It is certainly desirable to express all possible contact states within a single contact model. However, real-time demands and stability issues dictate the use of several contact models specialised to different contact states. While the model used for single finger contact is an extension of the virtual proxy (cf. RUSPINI et al. 1997), the two finger grasp requires new algorithms being stable on deformable objects and thin surfaces. We have therefore developed a contact model that is able to provide stable contact and information on the movement of the contact for tactile rendering, (cf. BÖTTCHER et al. 2008).

4.3 System Results

Since the purpose of the VR system was to bring the illusion of touching real fabrics to the user, it is important to know if the system is successful in resembling the perception. The analysis of the results provided the conclusion to the quality of the system in terms of haptic perception. By rating each fabric twice, a correlation between the two trials was used to estimate the "repeatability". The "consistency" in perception was obtained by correlating the ratings from the two subjects using the

VR system. Finally, correlating the mean ratings of real fabrics with the virtual counterparts estimates the ``realism" of the system. The summarised results given in Fig. 5 showing good correspondence of elasticity and roughness perception of system compared to touching real textiles. However, bending stiffness is not conveyed by the system as seen in the results. An explanation to this result is found in the deficiency in limited accuracy of the numerical simulation and the haptic device displaying the very small forces occurring in the bending.

Figure 5: *Evaluation results (cf. SUMMERS 2008)*

5 Conclusions

Haptic interaction with deformable physical objects poses a lot of interesting challenges. The conflicting requirements in terms of accuracy and performance make a compromise necessary. The two frameworks described in this paper each presented an own solution, respectively by decoupling the force feedback from the physical simulation and by defining a simplified local interaction model.

Interacting with hair represents a first step towards the enhancement of 3D hairstyle modelling. Long-term consequences include commercial benefits to the video games and movie sectors, but also to the areas of cosmetics and fashion, where such methods could foster the virtual prototyping of hairstyles and related care products. Manipulating virtual textiles can be useful in the textile industry to both the rapid prototyping and the artistic garment design process, as well as to future virtual consumer assessment facilities during online purchasing of clothes – as originally envisioned by the HAPTEX Project (cf. MAGNENAT-THALMANN et al., 2007).

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