Dissertation Abstract

Dissertation Title: A Study on Simulations of Granular Materials and Strands Taking Wetting Effects into Account
(吸湿現象を考慮した粒状および線状物体のシミュレーションに関する研究)

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There is considerable recent progress in physically-based simulations, driven by the high demands in computer animated movies. Realistic animations of rigid bodies, fluid, deformable objects and couplings among different objects became possible. However, simulating wetting effects between solid objects and water is still relatively in its infancy despite the fact that it is a common phenomenon in the real world. The main cause is the complexity of physical mechanism of the wetting effects. The wetting effects are interesting effects in our daily life and could greatly enrich the realism of games and animations.

An object that has water absorbency is called a porous medium. An internal structure of the porous medium consists of a solid part of the medium mixing with a vast number of pores. These pores result in the capillary action where water is absorbed into and flows through the medium. Pores inside porous media such as cloth and sponge have their locations fixed in the media, while pores in porous media such as granular material and hair are dynamically and temporally arise from complex contact regions among the media. This dissertation categorizes the former porous structure as a rigid porous structure and the latter as a deformable porous structure. Recently, novel approaches for wetting effects in the rigid porous structure have been proposed in the computer graphics field. However, only a few studies have been introduced for the deformable porous structures. Accordingly, this dissertation targets wetting effects in the deformable porous structures, especially, wetting effects in sands and hair strands which are the objects in our daily life and important in CG.

When granular material comes into contact with water, water is absorbed into pores among granular particles and diffused from particle to particle throughout the material by the influence of capillary action. Then, wet granular particles stick together due to liquid bridges that are formed between particles. The liquid bridges subsequently disappear when there is too much water penetrates into the material. The similar physical mechanism occurs in the case of hair as well. However, the wetting effects of hair are more complicated. There are three main differences from the granular material. First, a single hair strand is also a kind of porous medium. Water is absorbed not only into small contact regions among hair strands, but also into the inner layer of each hair strand. When water percolates into the inner layer of hair strand, a chemical reaction inside the strand causes the shape of the hair strand to temporally change. Second, the contact regions among hair strands are costly to examine, since a hair strand is a long cylindrical deformable object. Third, hair is an anisotropic porous medium, as water diffuses more in the hair strand direction.

To develop models for the wetting effects, the underlying simulation models for granular material and hair strands are also important. While well-studied particle systems can be used for simulating fine-scale of granular material, simulation of hair is still a challenging problem in computer graphics. Traditional simulation techniques handle hair as clumps or continuum for efficiency; however, the visual quality is limited because they cannot represent the fine-scale motion of individual hair strands. Although a recent mass-spring approach tackled the problem of simulating the dynamics of every strand of hair, it suffered from high computational cost and required a complicated setting of springs. The morphological shape transformation of wet hair requires a model that can easily modify the shape of hair, thus the recent models are not suitable. In this dissertation, the hair simulation model on such a fine-scale is built up from a novel single strand simulation model. Strand-like objects in our daily lives have a wide variety of materials, e.g., extensible and inextensible strands, rubber, threads, plastic. Such strand-like objects also exhibit interesting behaviors such as bending, twisting, tearing (by stretching or twisting), and bouncing back when pulled and released.

This dissertation presents a strand simulation model that enables these behaviors, handles wide variety of materials, and is suitable for building a hair simulation model for wetting effects. Specifically, this dissertation offers the following four contributions. First, this dissertation introduces a strand simulation model that based on Lattice Shape Matching (LSM), which has been successfully used for simulating deformable objects. Each strand is represented as a chain of particles, and its deformation are handled by geometrically-derived forces of the chain based on shape matching. The shape matching can simulate a stiff strand in a numerically stable way. This benefits in handling stiff hairstyles such as curly hair and afro. Second, this dissertation introduces a method for handling twisting effects with both uniform and non-uniform torsional rigidities. Third, this dissertation presents a method for estimating the tension acting on inextensible strands in order to reproduce tearing and flicking (bouncing back), whereas the tension for an extensible object can be computed via stretched length. The length of an inextensible object is maintained constant in general, and thus, a novel approach is needed. Fourth, this dissertation introduces an optimized grid-based collision detection for accelerating the computation. In the simulation of a large number of hair strands, this dissertation develops a GPU-based simulator which achieves visually-plausible animations consisting of several tens of thousands of hair strands at interactive rates.

For the wetting effects in granular material, this dissertation introduces a wetness value for each granular particle and integrates wet behaviors dependent on the wetness value into a simple particle-based framework. Using this method, a GPU-based simulator can achieve dynamic animations of granular material including wetting effects at interactive rates. For the wetting effects of hair, this dissertation introduces a simulation model that reproduces interactions between water and hair as a dynamic anisotropic porous medium. An Eulerian approach is utilized for capturing the complex deformable porous structure of hair and the wetting effects are efficiently handled using a Cartesian bounding grid. The proposed model and simulation generate many interesting effects of interactions between fine-detailed dynamic hair and water, i.e., water absorption and diffusion, cohesion of wet hair strands, water flow within the hair volume, water dripping from the wet hair strands and morphological shape transformations of wet hair.

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