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Physically based cloth simulation

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Abstract

In this paper, we describe a precise relationship between measured mechanical properties of cloth and the particle model. The proposed cloth model is compared with the tablecloth drape, furthermore it is validated by the visualization of cloth 3-D drapeability.

Introduction

As cloth modeling plays an even more important role in textile and apparel CAD/CAM and related areas, cloth model reflecting mechanical properties of the material becomes necessary.
Physically based cloth models have brought rapid progress to cloth simulation. The Finite Element Method (FEM), which is a popular technique to analyze deformation of elastic continuums, has been introduced to predict cloth drape[1].

Although FEM can give clear description of cloth mechanical properties, it is difficult to deal with complicated cloth dynamics. Moreover, it requires large amounts of memory to store the stiffness matrix describing the basic relationships between and among elements.

On the other hand, as cloth is a composite material constructed by warp and weft rather than a continuous sheet, discrete models describing cloth behavior with spring-mass or particle models have been proposed.[2]

Optimized techniques to accelerate numerical calculation have also been proposed[3]. However, the real mechanical properties of cloth are not involved in such models.

A particle system model
Based on the mechanical properties of woven cloth has first been proposed by Breen [4]. Measurement data of fabrics, produced by the Kawabata Evaluation System(KES) for woven fabrics are used. Their simulated tablecloths show obvious effect of different materials, however the simulation accuracy still remained a problem. Although their model has been extended to include cloth dynamics, the relation between the cloth dynamics and materials are not clear.

To solve the above problems in the particle model, we try to describe a clear and precise relationship between the particle model and cloth mechanical properties based on the KES measurement.

Theory

Woven cloth is represented by a particle system where each intersection corresponds to a particle. In the particle system, the mechanical behaviors consist of stretching and compression, bending, and shearing deformations, and non-linear are imagined acting on the yarn segments between crossing-point particles. Referring to Fig.1, the separation spring K_S exerts force Fs opposing separation of particles by other than the nominal distance σ ; the torsional spring K_B exerts torque T_B opposing bending along a thread line; and the torsional spring K_T exerts torque T_T opposing trellising between warp and weft threads.

$$F_S(r)=\begin{cases}-C_0(4r+\sigma)(r-\sigma)^4/\sigma^2 & r\le\sigma\\ 5C_0(r-\sigma)^4/\sigma^5 & r>\sigma\end{cases} \quad (1)$$

$$\begin{cases}T_B(\theta)=-\dfrac{987.8\sigma}{2}\left(\dfrac{\partial M(K)}{\partial K}+M(K)\right)\sin(\theta/2)\\ K(\theta)=\begin{cases}\dfrac{2}{\sigma}\cos(\theta/2) & \pi/4<\theta\le\pi\\ -\left(\dfrac{\pi}{4}\right)\beta/\theta+\alpha+\dfrac{\pi}{4}\beta & 0\le\theta\le\pi/4\end{cases}\end{cases} \quad (2)$$

$$(\alpha=\frac{2}{\sigma}\cos(\pi/8),\quad \beta=\frac{1}{\sigma}\sin(\pi/8))$$

$$T_T(\phi)=\frac{195.76\sigma^3}{4}F\cos\phi \quad (3)$$

Rather than using the KES stretch plot, we approximated the functions shown as equation (1) for the magnitude of separation spring force (F_S). However, the functions resulted in over stretching and compression of cloth.
Equation (2) and equation (3) represent the magnitudes of bending and shearing spring torques, determined by the differentiating their corresponding energy equations respectively. Here, the functions M(K) and F(ϕ) are obtained from the KES plots.

Furthermore, the bending force (F_B) actiequatng on a particle is calculated from the torque of the bending spring connecting to it along warp or weft direction, the shearing force (F_T) acting on a particle is obtained from the torques of the four trellising springs connecting to it. Consequently, the force acting on a particle is described as equation (4).

$$F = mg + F_S + F_B + F_T \quad (4)$$

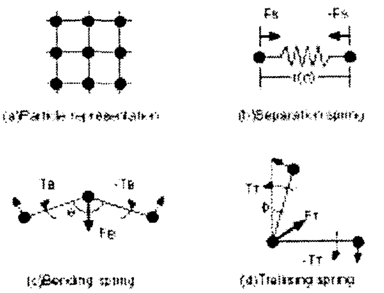


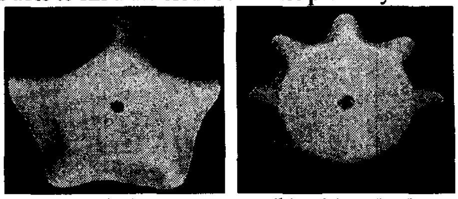
Fig.1 Particle Model

Results

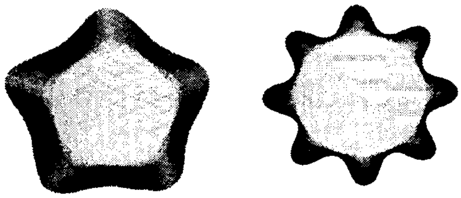
Using the particle model integrated with the collision model, we carry out experiments on two kinds of materials: thick cotton and thin wool. Fig.2 shows a thin wool tablecloth(40[cm] × 40[cm]) put on a table(20[cm] × 20[cm]).

Fig.2 Tablecloth Simulation

To validate the particle model further, it is applied to simulate the drape test which is used to measure cloth drapeability. In the drape test, a circular cloth sample whose diameter is 10[in.] is put on a disk of a drapemeter whose diameter is 5[in.].The 3-D shape formed by the sample is used to evaluate cloth 3-D drapeability, which affects clothing drape directly. In fig.3, (a) and (b) show the top views of the real test results of samples: thick cotton and thin wool; (c) and (d) show the respective virtual drape test generated by the proposed particle model. The thick cotton sample results in fewer folds due to its higher bending and shearing rigidities, while the thin wool one forms more full folds and shows good drapeability. The simulation shows consistent results with it, and confirms that the modified particle model is able to simulate cloth behaviors precisely.



(a)Thick Cotton (b) Thin Wool



(c)Thick Cotton (d) Thin Wool

Fig.3 Drape Simulation

Conclusions

We have described a clear and precise relationship between measured mechanical properties of woven cloth and the particle model in this paper. The experiments involving a tablecloth drape, drape tests have demonstrated that, the proposed model can not only simulate cloth drape accurately, but also visualize cloth dynamics depending on cloth mechanical properties.

As mentioned above, the cloth hysteresis is not exhibitted in this work while hysteresis has important effects on cloth aesthetic appearance, especially dynamic behaviors. Thus, to model the internal friction, which is mostly accounted for the energy loss in cloth, into the particle system will be our next work.

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