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Combination of Implicit Integration and Collision Response for Cloth Simulation

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Abstract

This paper implements efficient techniques for cloth simulation in the area of cloth model, numerical integration, collision detection and response. The whole procedure combines the accurate bending model with implicit integration and collision response. Collision response remains a serious difficulty in cloth simulation, especially with implicit integration. We propose a general scheme that integrates collision response into implicit models recovering most of the nice draping movements of the cloth. Collision detection between human body and cloth is accelerated by Axis Aligned Bounding Box (AABB). A cloth draped on a human model is tested for the combined techniques we put forward. Experimental results reveal that this procedure is suitable for the accurate cloth simulation which preserves folds and wrinkles. The scheme that combines implicit integration and two-stage collision response is efficient for cloth simulation.

Keywords: Implicit Integration; Collision Response; Combination; Cloth Simulation

1 Introduction

The technology involved in virtual sewing and draping is generally regarded as a physically-based method. Among which, continuum approach [1-6] and particle-based approach [7-12] are often referred. Feynman's model [6] for generating the appearance of cloth is one of the earliest works. By regarding the cloth object as an elastic plate, the final drape was computed by finding the minimum value of the energy equation. In the work of Terzopoulos et al. [1], the cloth object was also represented as an elastic object. However this method suffers from instability problems that decrease overall performance. The first milestone of non-continuum approach was set by Breen et al. [8] in their famous particle-based model to predict the draping behavior of woven cloth. The cloth object was represented as an interlaced particle system. The method was devised to achieve the final equilibrium state of specific materials. Energy minimization was also employed to determine the equilibrium position. The drawback of this method is that it cannot produce

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transitions between the initial state and the final equilibrium. Years later, House et al. [13] extended this model with force-based techniques, which was very similar with the most popular mass-spring model proposed by Provot [12] in 1995. Actually, the major contribution of Provot is his attempt to describe the rigid behavior of cloth with a position adjustment method to overcome the super-elasticity, which is a hot topic in many physically-based methods [14-24]. Eberhardt et al. [9] expanded the particle-based model by incorporating hysteresis and creases to create a dynamic simulation method based on a Lagrangian formulation. Baraff and Witkin [11] used a continuum approach on each triangle for in-plane deformation and the angle between adjacent triangles to measure out-of-plane deformation, their implicit integration scheme was the most advocated method in recent years.

Collision handling remains a serious difficulty in cloth simulation, especially with implicit integration. We propose a general scheme that integrates collision response into implicit Euler models instead of implicit Midpoint method [25] recovering most of the nice draping movements of the cloth.

2 Algorithms

2.1 Physical Model

The present work employs a mass-spring system [12] for garments based on triangular mesh. Each vertex is considered as a mass and the triangle edges are considered as the springs. The stretching and shearing resistance is enforced by applying the spring force along each edge in Eq. (1).

$$\mathbf{f} = \mathbf{f}_{\mathrm{i}} + \mathbf{d}_{\mathrm{i}} = -k\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_{\mathrm{i}}}\mathbf{C}(\mathbf{x}) - k_d\frac{\partial \mathbf{C}(\mathbf{x})}{\partial \mathbf{x}_{\mathrm{i}}}\mathbf{C}(\mathbf{x}) \tag{1}$$

where $\mathbf{f}_{\mathrm{i}}$ and $\mathbf{d}_{\mathrm{i}}$ are the elastic force and damping force applied onto ith mass. $\mathbf{C}$ is the conditional function. By defining $\mathbf{C} = |\mathbf{x}_{\mathrm{ij}}| - L$, we have:

$$\mathbf{f}_{\mathrm{i}} = \begin{cases} k_s(|\mathbf{x}_{\mathrm{ij}}| - L)\dfrac{\mathbf{X}_{\mathrm{ij}}}{|\mathbf{x}_{\mathrm{ij}}|} : & |\mathbf{x}_{\mathrm{ij}}| \geq L \\ 0 : & |\mathbf{x}_{\mathrm{ij}}| < L \end{cases}$$

where $\mathbf{x}_{\mathrm{ij}} = \mathbf{x}_{\mathrm{j}} - \mathbf{x}_{\mathrm{i}}$, L is the rest length between ith and jth masses.

The bending resistance is enforced by resisting the rotation among two adjacent triangles who shares the same edge as illuminated in Fig. 1. The bending force is implemented as in the work of Bridson et al. [26] in Eq. (2).

$$\mathbf{f} = \mathbf{f}_{\mathrm{i}}^{\mathrm{e}} + \mathbf{f}_{\mathrm{i}}^{\mathrm{d}} = k_e\frac{|\mathbf{E}|^2}{|\mathbf{N}_1| + |\mathbf{N}_2|}(\sin(\theta/2))\mathbf{u}_{\mathrm{i}} - k_d|\mathbf{E}|(\mathbf{u} \otimes \mathbf{u})\mathbf{v} \tag{2}$$

$$\mathbf{u}_1 = |\mathbf{E}|\frac{\mathbf{N}_1}{|\mathbf{N}_1|^2}, \quad \mathbf{u}_3 = \frac{(\mathbf{x}_1 - \mathbf{x}_4)\cdot\mathbf{E}}{|\mathbf{E}|}\frac{\mathbf{N}_1}{|\mathbf{N}_1|^2} + \frac{(\mathbf{x}_2 - \mathbf{x}_4)\cdot\mathbf{E}}{|\mathbf{E}|}\frac{\mathbf{N}_2}{|\mathbf{N}_2|^2}$$

$$\mathbf{u}_2 = |\mathbf{E}|\frac{\mathbf{N}_2}{|\mathbf{N}_2|^2}, \quad \mathbf{u}_4 = \frac{(\mathbf{x}_1 - \mathbf{x}_3)\cdot\mathbf{E}}{|\mathbf{E}|}\frac{\mathbf{N}_1}{|\mathbf{N}_1|^2} - \frac{(\mathbf{x}_2 - \mathbf{x}_3)\cdot\mathbf{E}}{|\mathbf{E}|}\frac{\mathbf{N}_2}{|\mathbf{N}_2|^2}$$