COMPARISON BETWEEN ADAPTIVE REFINEMENT AND ADAPTIVE COARSENING FOR SIMULATING REALISTIC FORCE AND SHAPE OF VIRTUAL CLOTH

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ABSTRACT

Shape as well as force is required to represent the cloth in virtual environment. A model, based on the cost functions, realizes the shape together with force by using physical data obtained from Kawabata Evaluation System. However, cost/ energy minimization technique is very slow that restricts the increase of mesh density. Some of previous work has employed the adaptive refinement in this regard. However, mesh simplification is not considered. We propose a method, which proceeds in the reverse direction of refinement. Simulation starts with denser mesh of cloth and mesh density is reduced adaptively during simulation, which we say the 'Adaptive Coarsening'. This paper describes the comparison between adaptive refinement and adaptive coarsening. We found that adaptive coarsening is comparatively better in terms of speed and quality for cloth simulation.

Key Words: Cloth Simulation, Adaptive Coarsening and Adaptive Refinement.

1. INTRODUCTION

Cloth is a deformable object and its properties lies between elastic and rigid material. There are three models, mass-spring model, finite element model and particle-based model, which are usually used to simulate the cloth. A model describes the particular properties of cloth such as material (Wool, Cotton) and mechanical (Bend, Shear, Stretch) properties. Force integration [2,3] or energy minimization [1,4,6] techniques have been used for the static and dynamic simulation of cloth.

In computer graphics, many approaches have been proposed for the visual representation of geometrical deformation of the cloth. However, only visual information is not enough for virtual manipulation. User can only see the generated images or animation but can't feel it. In the field of mechanical engineering, researchers have worked on manipulating the force (haptic) feedback to represent the mechanical parameters. However, relation between force and shape deformation is not considered especially for cloth like objects. Anyhow, both shape and force are needed to represent the cloth in virtual environment.

We are using particle-based model that utilizes the experimental data obtained from Kawabata Evaluation System (KES). We have developed the model based on minimization to simulate the consistency between shape and force [4]. It requires the reality of shape, reality of force and reality of relation between force and shape. Minimization techniques are slower and limit the mesh resolution. Cloth has variety of visual (drape) effects and its realistic representation needs fine discretization. However, it requires large computational time. One solution is to use adaptive meshes to raise the mesh density under the controlled amount of time. Previous work [2,3,5,7] employs the adaptive refinement in different ways and for different applications, but adaptive coarsening is not considered. We initiate the idea of starting simulation with higher mesh density and decrease the density adaptively, which we call the 'Adaptive Coarsening'.

This paper includes the implementation of adaptive refining as well as coarsening and compares the two techniques. Section **2** contains the brief review of previous work including the Kawabata Evaluation System. The particle-based model, which is used for the simulation of shape and force, is explained in section **3** and its detail is given in [4]. The procedure for adaptive refinement and coarsening is given in section **4**. Section **5** lays out the simulated images of cloth. Finally conclusion is presented in section **6**.

2. RELATED PREVIOUS WORK

Kawabata Evaluation System (KES) is a fabric-testing device, which is globally used to measure the stretching, bending, shearing and other properties of cloth. KES characteristics, which describe the relation between force and shape, are unidirectional (force to shape or vice versa) and hysteretic. Also there exists more than one hysteretic cycles depending on the manipulation. We have to do simulation by keeping these limitations in our mind.

Breen et al. [1] employs KES data for bending and shearing to simulate the shape of cloth. KES data for both bending and shearing describes unilateral relation from shape to force. So this technique is not applicable to simulate the force together with shape. Considering the different unilateral relation of KES data for stretch and bend, Sakaguchi et al. [6] has simulated the shape of cloth in two phases. The KES data for bend is employed in phase-I with Newton's law while KES data for stretch is employed in phase-II. However, at the end of simulation, shape and force are not consistent with each other. Different from these two approaches, we [4] have simulated the shape and force at the same time by considering that KES data describes the state transition for specific history of manipulation.

Since cloth has variety of visual effects, its realistic representation needs a very dense mesh, which increases the computational cost. One way is to use the meshes of different densities at different stages of simulation [7]. Its implementation is simple because of uniform meshes but this scheme un-necessarily refines some part of mesh. An optimum discretization can be achieved by employing the adaptive meshing.

Constant mesh resolution is used in [2] and goal of the refinement is to prohibit the cloth penetration in the colliding object. All new inserted particles are non-active and have no role in the simulation. Actually it has no relation with the physical properties of cloth. Hutchinson [3] adaptively refines the mass-spring mesh on the basis of bending angle. Different time steps are used for simulation. There is no information how they treated with the bending springs. A bending spring directly connects a particle P_i with P_{i+2} and calculation is independent of P_{i+1}. When a new particle is inserted between P_i and P_{i+1} then this bending spring is no longer valid. Similarly if P_{i+1} is removed then this bending spring reflects the stretching behavior. Later Villard [5] considers three nodes making two beams instead of bending spring. Bending curvature is calculated as the function of lengths of two beams. In this way bending property is justified. In our model, bending curvature and moment are calculated on the basis of three particles those are making the bending angle. Thus we do not need extra efforts to accommodate the mechanical parameters. Previous work considers the refining only while we are considering the coarsening as well as refinement.

3. CLOTH MODEL

We have developed cloth model by considering three main assumptions. 1) Initial state at each simulation step works as internal variable, which keeps the track of previous history. 2) KES curve works as boundary value. 3) All other hysteretic cycles lie within this boundary. The detail is available in [4].

Cloth is divided into ***I X J*** mesh of particles. The crossing of warp and weft thread represents a particle. Two adjacent particles make an edge, which reflects the stretching property. Similarly three adjacent particles make a triple that is used to calculate the bending angle and curvature as shown in Fig. (1). $\mathbf{X}_{ij}$ is the position of a particle, f^s is the internal stretching force of an edge and f^b is the bending force for a triple. All other variables are function of above variables.

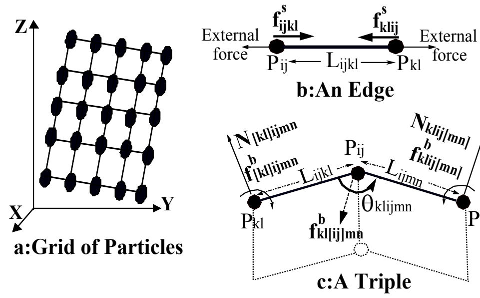

Fig. (1): Cloth model

3.1. Energy / Cost Functions and Minimization

We consider the three factors, motion & gravitation ($\mathbf{E}^{\mathbf{n}}$), Stretching ($\mathbf{E}^{\mathbf{s}}$) and Bending ($\mathbf{E}^{\mathbf{b}}$), which are affecting the cloth. We choose the stretching and bending properties because KES stretch curve is a relation from force to shape while KES bend curve describes the relation from shape to force. On the other hand Newton's law describes the bilateral relation between force and shape. So we are able to involve the force as well as shape at the same time. Other properties (like shearing) are the same as stretch or bend and can be included in the similar way. Each cost function is defined based on the KES data, which represents the amount of violation from KES data. The cost is zero when the calculated data lies within or on the KES curve and cost is increasing outside the KES curve. The total cost function is the sum of all cost functions due to these factors.

$$\mathbf{E} = C_n \mathbf{E}^{\mathbf{n}} + C_s \mathbf{E}^{\mathbf{s}} + C_b \mathbf{E}^{\mathbf{b}}$$

Minimization of cost function gives the values of desired variables, which satisfies the equilibrium state of cloth. We have used the simplest one 'Steepest Descent' scheme for minimization but it takes very long time. Then we replace it by the 'Conjugate Gradient' method, which has improved the speed.

3.2. Experiments for Verification

We have performed experiment to verify our model. First we take the rectangle piece of cloth and apply the same procedure as done in the KES to measure the bending and stretching property. We have successfully reproduced the same result as obtained by KES approximately. Another experiment is performed, which depicts that state transition under the arbitrary history of manipulation traces a continuous path and lies within or around the KES curve. It verifies our assumptions, in our simulation model [4].

4. ADAPTIVE MESHES

After developing the model, question arises how to increase the realism and speed? Realism and speed have opposite response when mesh becomes denser. An efficient model needs the optimum number of particles in the mesh. The ultimate solution is to use the adaptive mesh size. Its implementation is difficult but mesh density is optimum. It can be implemented as a) Adaptive Refinement or b) Adaptive Coarsening. In previous work, researchers have not employed the adaptive coarsening. We are implementing these two schemes in this work.

There are three important factors to be considered for employing the adaptive meshes.

1. Mass conservation and force distribution
2. Adjusting the mechanical parameters.
3. Updating the data structure

4.1. Refinement Criteria

As shape is concerned, user can easily visualize the bending of cloth as compared to stretching. Previous work has refined the mesh based on the bending angle or curvature [3,5]. Similarly we are also using the bending cost function in this regard. However, we are aiming to examine the cloth by refining/coarsening the mesh with respect to bending as well as stretching cost function.

4.2. Adaptive Mesh Refinement

In refinement, initial mesh is coarser one and new particles are added on demand. The boundary particles need special care for refinement. It also requires avoiding from duplication in the data structure. A particle is refined when bending function exceeds from threshold value. Refinement of a particle, adds eight new active particles and eight new ghost particles as shown in the Fig. (2). Ghost particles do not take part in simulation and are just used to maintain the topology of mesh. A new particle represents the ¼ of the area as compared to coarser particle in the above level of refinement. The length of new edge is halved in next finer mesh.

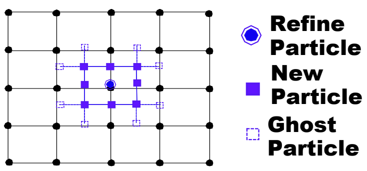

Fig (2): Mesh refinement

4.3. Adaptive Mesh Coarsening

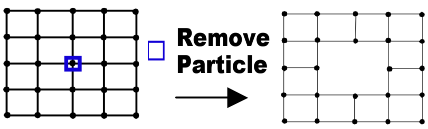

Fig (3): Mesh Coarsening

It is the reverse operation of refinement. It requires same conditions as that of refinement. Initially cloth has finest mesh and coarsening omits particles, which have very small bending cost function. It does not affect the overall cost function too much. Removal of a particle also eliminates four edges and six triples those are attached with this particle as shown in Fig. (3). Edges and triples are merged / shuffled around the particle whose both sides have been coarsened.

4.4. Adjusting Mechanical Model

The distance between two particles is halved by the refinement while the coarsening doubles it. KES characteristic, for both bend and stretch, are produced for a specific size of cloth. Our model normalizes the values during the interpolation of KES curves accordingly. So there is no problem in employing KES data for refinement or coarsening.

In contrast to mass-spring model, calculation of bending angle in our model involves the all three particles of a triple and enables us to add or remove a particle from mesh. Removal of a particle merges a triple and an edge in weft (see Fig (4-left)) and warp directions. Triple ***T2*** is merged in the triples ***T1*** & ***T3***, as a result force can be divided equally between ***T1*** & ***T3***. Similarly merging of edges ***E2*** & ***E3***, adds forces for resultant edge as shown in Fig (4-right).

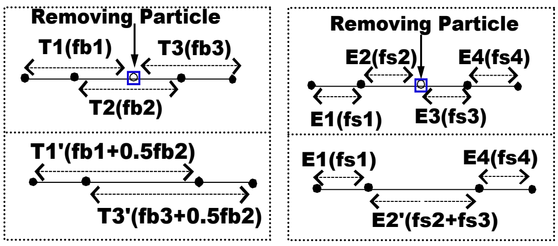

Fig (4): Removing a particle

Refinement process decreases the length of an edge to half and area around an edge becomes ¼. The space having 4 edges is represented by 16 edges after refinement as shown in Fig (2). The uniform force distribution will assign the $f^s/4$ to the finer edges.

As area represented by the finer particle is ¼, so mass is reduced to ¼ for finer particle. In this way total mass can be preserved, but different masses show different responses that should be tackled carefully. To have the same response, one way is to take the heavier mass as for coarser mesh and adjust it when calculating the stretching or bending. The other way is to take the lighter masses (like concept of mass density) as for finest mesh by considering that whole mesh is refined and coarser area contains more non-active / ghost particles. We are using the latter concept and it remains valid in adaptive coarsening.

5. EXPERIMENTAL RESULTS

We have simulated the rectangular piece of cloth draping over the box whose one corner is fixed by the user. Fig. (5) depicts that cloth is penetrating in the box and needs denser mesh. By employing the finer mesh, adaptive refinement and adaptive coarsening, images are generated as shown in Fig. (6, 7 & 8) respectively.

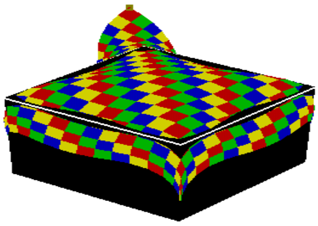

Fig (5): Simulated image with coarser mesh

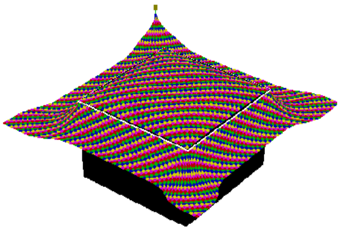

Fig (6): Simulated image with finer mesh

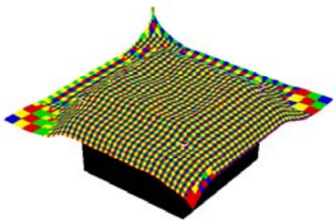

Fig (7): Simulated image with adaptive refinement

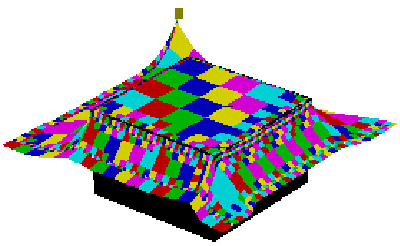

Fig (8): Simulated image with adaptive coarsening

The cost function represents the violation of cloth parameters from experimental data. The simulation is same as real one when cost function is zero. Therefore, minimized value of cost function indicates the quality of simulation. The cost value of finer mesh is considered as zero quality error for comparison. The comparison among different simulation for time and quality error is given in Table 1. Results show that adaptive coarsening is better than coarsening.

TABLE 1: COMPARISON

	Time (sec)	No. Of Particles	Quality Error
Coarser	180	400	+0.1468
Finer	3200	5939	0.0
Adaptive Refinement	1855	400-4689	+0.0625
Adaptive Coarsening	700	5939-1600	+0.035

6. CONCLUSION

Different form adaptive refinement, adaptive coarsening starts with finer mesh of cloth. Mesh density decreases inside the minimization process to search a stable state for cloth. Coarsening is slower for early iterations because of larger mesh but we observed that overall time is less than refinement (See Table 1).

As refinement introduces the new particles, it requires defining the links between new and old particles. On the other hand, coarsening process omits the element of cloth structure. So, it is simple and needs less effort for managing the data structure.

Linking of new particles and distribution of forces may increase the error level during refinement. In contrast to finite element methods, refinement maintains or increases value of cost function. Since we are using the cost minimization technique, it may increase the number of iteration for minimization. Besides this, coarsening removes the elements, which have small cost function. Therefore, cost function may decrease or maintain the previous value. We have examined the value of cost function after the coarsening for confirmation. This feature makes minimization process more stable.

7. REFERENCES

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