QUANTITATIVELY COMPARING
VIRTUAL AND REAL DRAPING OF CLOTHES

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ABSTRACT

Several cloth modeling techniques have been proposed. Their main purpose is the realistic simulation of the garments of virtual actors for entertainment and advertising. In these areas, the main concern is to construct fast algorithms, able to produce impressive and qualitatively satisfactory draping of clothes. Other applications, as designing, manufacturing and selling real garments, call for a virtual draping which not only satisfies the human eye, but also closely mimics the real physical draping of clothes. From this viewpoint we will discuss some modeling techniques, and present some result concerning the quantitative comparison between the draping of real clothes and their virtual counterpart.

Keywords: computer graphics, virtual draping algorithms, Kawabata tests, quantitative comparison.

1. INTRODUCTION

A central problem in computer graphics is modeling physical phenomena in order to obtain realistic images and animations. In recent years, several researchers have dealt with the problem of modeling cloth. A number of physically-based draping algorithms have been proposed. Synthetic images or animations of simple objects such as flags and tablecloths, as well as of complex garments, interacting with other synthetic objects, are now common experience. The reader is referred to [Ng96], [Baraf98a], [Breen94], [Eisch00] for a comprehensive set of references .

For application areas as entertainment or advertising, the main concern is to construct fast and flexible draping programs, able to produce realistic-looking images. These tools can benefit of physically-based models which can easily produce images that are satisfactory for an average human observer.

However, many other promising applications areas exist. The use of cloth modeling tools could change much in textile industry. CAD systems allowing to design virtual garments can speedup drastically the design process, without cutting and sewing the real fabric. This is of paramount importance in the fast changing world of fashion. Other applications can be foreseen in the fashion business, such as virtual fashion-shows, or virtual fitting rooms at the retailers. It is clear that in most of these cases the requirements of the draping programs are more strict than in the entertainment field. Close, quantitative resemblance between physical and virtual draping appears necessary. Also computer-aided robotic manufacturing of clothes or other textile-based products could benefit from exact draping programs.

In all these cases, the draping systems should be able to deal with several kind of clothes with different physical behavior. Thus, it is necessary to be able to change some parameters of the model according to some measures performed on the real cloth. One way for extracting significant empirical data is the *Kawabata Evaluation System* [Kawabata80].

Although much work in this direction has been made, a number of important questions remain open. Among them: which model of cloth is more suitable? How to map the empirical data on the model? How far is the virtual draping from the real one? In which way simplifications of these data (non linear and with hysteretic behavior) affect the draping?

Without any doubt, to fully answer these question is a very requiring task. However, it is necessary to investigate thoroughly these problems for constructing draping programs which closely mimics the physical behavior of clothes.

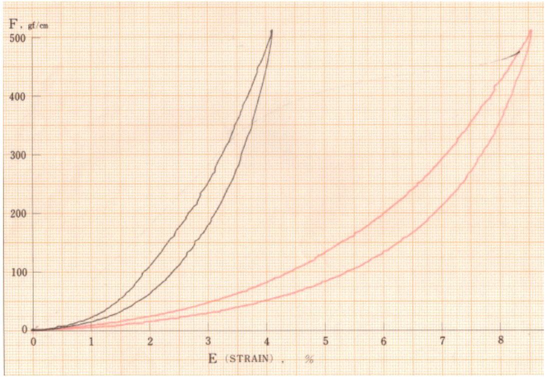
In this paper we will present some preliminary results concerning quantitative comparisons between real draping and virtual draping based on the Kawabata data.

2. BACKGROUND

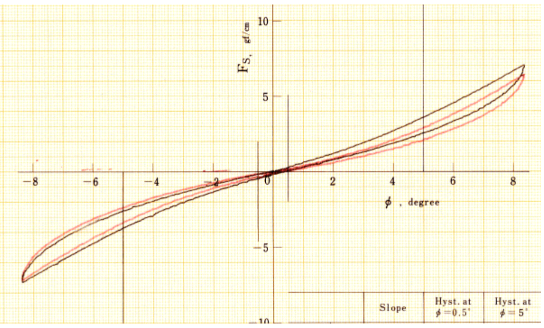
2.1 The Kawabata Evaluation System

Woven cloth is a complex physical system, essentially anisotropic, non linear and showing hysteretic behavior.

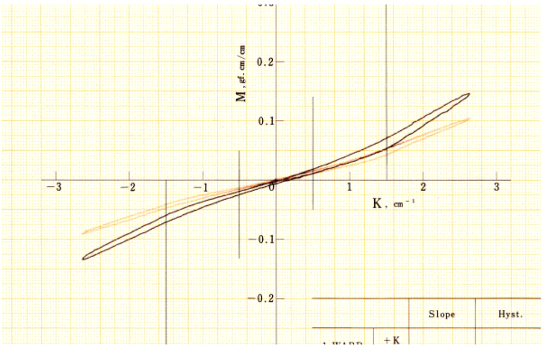
Most of the physical properties of woven cloth are captured by the empirical Kawabata Evaluation System [Kawabata80]. It consists of a standard equipment, able to determine the relations between stress and strain for stretching, shearing and bending in both warp and weft directions, as well as other properties which do not concern draping. The measure of the Poisson ratio is not included in these tests. It is worth noting that the Kawabata plots for a given cloth can be very different for warp and weft directions, and thus they quantitatively capture the anisotropic behavior of the cloth, as well as its hysteretic behavior. It is hoped that the Kawabata data of set of different clothes, simplified in some way, could be at the basis of effective textile CAD systems.



Tensile
Fig. 1



Shear
Fig. 2



Bending
Fig. 3

In Fig. 1-Fig. 3 we show the Kawabata diagrams of one of the cloth we have used for our experiments.

2.2 Discrete models

Many physically-based techniques for modeling cloth has been presented in the last few years. A number of researchers have constructed their models from continuos deformable systems, as for instance [Terzo88], [Eisch96] and [Eisch00]. However, several recent draping algorithms use directly discrete models. The general idea is to model small contiguous areas of cloth as interacting mass points constrained in a polygonal mesh (see [Breen94], [Eberh96], [Volin95], [DeRose96], [Baraf98a]). The main reason is probably that these models allows straightforward handling of collisions, friction and in general of interactions with other virtual objects. In addition, polygonal meshes are a common tool for graphic libraries.

Computing the static draping of a cloth or an animated sequence has been made either by directly integrating of the Newton laws of motion, or by minimizing the energy function. This can affect more or less heavily the simulation [Baraf98a], but is not of direct concern of this paper. Anyway, minimizing energy functions is not apt to deal with hysteretic behavior.

2.3 Comparison between virtual and real draping

In order to obtain the realistic emulation of the draping of a given cloth, several authors have mapped physical data, mostly Kawabata data, on the parameters of their models. However, to our knowledge, very little has been reported in the area of *quantitative* comparison between virtual and real draping.

Traditional real drape test attempted to evaluate the overall draping behavior of a cloth by measuring the number of folds and the area covered by the folds of a circular piece of cloth over a pedestal (*Drapmeter*). These measures have been used in [Colli91] for quantitatively evaluating a cloth modeling system based on orthotropic shell theory and Kawabata data.

Breen [Breen94] directly modeled the cloth as a rectangular mesh of mass points, or particles. Using an energy approach, he neglected the stretch energy, usually small if the draping is due only to the cloth's weight, and obtained bending and shearing energies by approximating the Kawabata plots with linear and quadratic segments, neglecting hysteresis. He showed images of real and virtual tablecloths. The images appeared similar, but no quantitative data were reported.

A similar approach was used in [Eberh96] for the model and its parameter, but only virtual draping images were shown in this paper.

Several other papers describe physically-based models, and show virtual draping images, at most together with real images for qualitative comparison, as for instance [Eisch96] or [Au00].

3. A POSSIBLE APPROACH TO A QUANTITATIVE COMPARISON

We have seen in the previous section that quantitatively comparing real and virtual draping is practically an unexplored area. We think that it probably calls for a variety of techniques, depending not only on the purpose of the draping simulation and the type of cloth, but also on the size of the cloth, the object interacting, the forces involved and several other factors.

One way for approaching this intricate problem is to roughly divide the draping in different categories. First we must consider the general category of clothes which drape only for their own weight.

Within this general case, one category could be qualified as "large and irregular draping". Broadly speaking, this draping takes place when the piece of cloth is large and has many folds. In addition, this kind of draping is irregular because of the interacting objects, the way in which the equilibrium position has been reached, or both. First, it is clear that this kind of draping is affected by non linear friction and hysteretic behavior, and thus the simulation model must take into account these complex phenomena. Second, friction and hysteresis combined with small variations of the initial position and of the local parameters of the objects involved can produce *infinite* different draping configurations. Clearly, it is pointless attempting to compare the real and virtual draping in detail, wrinkle by wrinkle. This case calls for the extraction of synthetic parameters, extending the idea of the Drapmeter, which unfortunately is restricted to circular tablecloth. One possible way of doing this is computing some kind of transform, as the 2D Fourier Transform, which could capture the general characteristic of the draping. We are now experimenting this approach.

Another category, which is the object of the experiments presented in this paper, refers to "simple" draping, that is with few folds. We will also consider cases where the effect of friction of the cloth with itself or other object can be neglected, so that a few equilibrium positions are possible. Finally, the simple cases we consider are actually 3D, and involve stretching, shearing and bending.

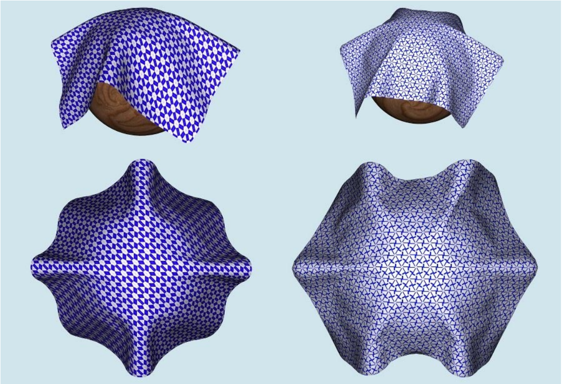
In the following sections we report quantitative measurements of the 3D geometry of real cloth, and compare these data with the corresponding data obtained from the virtual cloth draped according to the Kawabata parameters.

We also report some results concerning the effect of using different levels of accuracy of the model and different discretization resolutions.

4. THE MODEL USED

Different cloth models have been proposed. Many of them are able to capture the cloth general behavior; however the real problem is to understand how to map the physical parameters on the model. In our implementation, we have decided to model directly the cloth as a polygonal surface.

Several models of this kind use triangular meshes, as [Baraf98a], [Volin95] and [DeRos98]. Triangular elements have some advantages, for instance when modeling irregular pieces of cloths to be assembled in virtual garments. However, this model is not strictly consistent with the microscopic structure of woven cloth, consisting of two orthogonal sets of threads. A triangular mesh, although effective for fast animation and collision detection, can produce artifacts as those shown in Fig. 4, where a fabric drapes over a sphere.



Fabric draping over a sphere using a quadrangular mesh (left) and a triangular mesh (right)
Fig. 4

Our simulator models the cloth as a rectangular mesh which captures more closely the characteristics of the cloth, that is its anisotropic structure, and thus looks more suitable to map the Kawabata data.

The cloth can be discretized at different resolutions; given a system of *n* particles, each particle has the following attributes:

- position $x \in \Re^3$
- velocity $v = \dot{x}$
- mass *m*, which is determined dividing the product of cloth's density and patch area by the total number of particles
- the net force *f* applied to the particle; the acceleration of the particle is hence given by $\ddot{x} = f / m$
- state (blocked/free)

The dynamical simulation of the physical behaviour of cloth involves evaluating all the forces acting on each single particle over time. Forces can be both internal, such as stretching, shearing and bending, and external, such as gravity, air resistance or interactions with other objects.

The algorithm implemented by the draping simulator is depicted in Fig. 5. The system of differential equations is solved using a Runge-Kutta method of the fourth order.

Collisions between the cloth and external objects or self collisions are handled after the integration step.

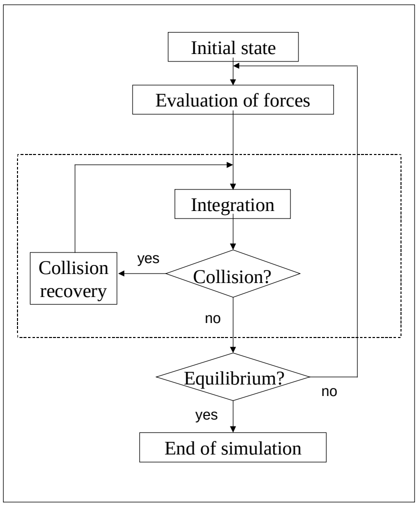


Fig. 5

Since our method evaluates the evolution of each particle from its initial state to the final position, it could be possible to take into account also the hysteretical behaviour of cloth's parameters. This will be the object of future work.

In the following paragraphs we describe how internal forces, external forces and collisions are expressed by our model.

4.1 Internal forces

As internal forces we consider stretching, shearing and bending. Stretching is modeled with springs between adjacent particles in the warp and weft directions. The values of the spring constants can be obtained from the Kawabata plot shown in Fig. 1. The value K_{st} applied is derived as follows:

$$K_{st,d} = \frac{f_{st,d}(\varepsilon)}{\varepsilon}$$

where *d* indicates the orientation (warp or weft) and $f_{st,d}(\varepsilon)$ is the force per unit length obtained from the Kawabata diagram as a function of the percentile elongation ε.

Also shearing is modelled with a set of springs which lay along the diagonals of each cell of the particle system. This model does not allow to distinguish between warp and weft, like other model as that of [Eberh96], since the diagonal springs act on both directions. Thus, the two spring constants are equal and are taken as a combination of the two constants extracted from the Kawabata diagram shown in Fig. 2. The constants of the stretching springs should be modified accordingly. Their values are set as follows:

$$K_{diag} = \tfrac{1}{2sin(\alpha)}(f_{sh,warp}(\alpha) + f_{sh,weft}(\alpha))$$
$$K'_{st,warp} = K_{st,warp} - K_{diag}$$
$$K'_{st,weft} = K_{st,weft} - K_{diag}$$

where α is the mean angle of deformation of the cell and the $f_{sh,d}(\alpha)$ are the values obtained for each direction *d* from the Kawabata diagram as a function of α.

The bending force is modelled evaluating the curvature of the cloth surface at the particle location for warp and weft direction. The Kawabata diagram in Fig. 3 plots the bending moment per unit length as a function of the curvature. Thus, knowing the geometry of the particle system, we can derive first the bending moment and then the bending force applied to each particle.

Further details can be found in [Scala00].

4.2 External forces

The external forces include the gravity, the air resistance and friction. To improve stability, as suggested by [Baraf98b], we introduced a damping force:

$$F_{damp} = -\beta \cdot v$$

4.3 Collisions

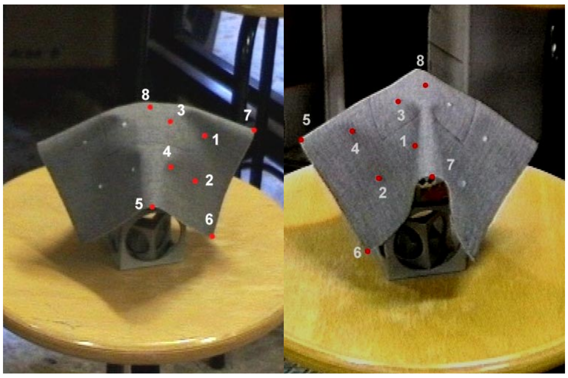
Collisions can fall into two main categories: collisions with external objects and self collisions (that is cloth/cloth collisions).

In both cases, given the starting position x_t of a particle and its position x_{t+dt} after the integration step, there is collision if the segment x_t-x_{t+dt} intersects the surface of the external object or of the cloth itself.

When collision is detected, a simple solution is to modify the particle positions. However, this method may introduce strong stretching reactions which alter the correct behavior of cloth. A better solution is to backtrack the simulation until the first collision time of all the colliding particles. The components of the total force and velocity of the colliding particles normal to the contact surface are zeroed at collision time, since we can consider the collision as inelastic. In this way the dynamic of each particle evolves according to the correct state of its neighbors. The tangent components are left unchanged, since in our simulation friction is not considered.

5. THE EXPERIMENTAL SET-UP

For measuring the shape of the real 3D draping of a piece of cloth we use the following technique. The cloth is marked with a rectangular grid of points which are a subset of the points used to model the virtual cloth. The cloth is observed by two cameras in fixed positions. More cameras can be used for improving precision. Each camera has been calibrated according to the Tsai technique [Tsai87]. From the different locations of the grid points on different images, their 3D position can be computed (see Fig. 6).



Two different views of the same cloth showing some of the reference points

Fig. 6

The objects interacting with the real cloth and its constraints are reproduced in the virtual environment, so that the virtual cloth drapes in similar conditions. The parameter used to measure the precision of the reconstruction is the mean distance between corresponding points on the real and on the virtual cloth. The experimental set-up also allows to measure how simulation is affected using different resolutions of the particle grid and different levels of accuracy in approximating cloth parameters.

One problem we met was how to manage hysteresis. The information extracted from the Kawabata diagrams are not suitable for direct use into the simulator, since they refer to the behaviour of the cloth during the Kawabata tests and no direct information is given about other hysteresis cycles.

To solve this problem, the hysteresis cycle has been approximated with a single curve. As can be seen in Fig. 1-Fig. 3, the two branches of the hysteresis cycle are very close, especially for shearing and bending, so they can be merged together. This happens for many kinds of clothes. Hysteresis is more relevant for stretching. However, in the experiments presented the cloth deformations are due only to gravity and the area of interest in the Kawabata diagram is very close to the origin, where, again, hysteresis can be neglected.

For shearing and bending, the Kawabata tests provide two values, *shear stiffness* (G) and *bending rigidity* (B), defined as the mean slope of the respective diagram in its linear area (for shearing, a deformation between -5 and 5 degrees; for bending, a curvature between -1.5 and 1.5 cm^{-1}). Hence, a simple approximation of those diagrams is a line whose slope equals G and B, respectively. For stretching, a similar value is not provided. However, as stated above, we can use the mean slope of the diagram close to the origin.

A more accurate estimate of the diagrams can be obtained using a piecewise linear curve.

Several experiments have been carried out, as detailed in the following subsections. Two different fabrics have been used:

- a 20x20 cm patch of a cotton-like fabric, having density of 138 g/m^2 (patch A)
- a 20x20 cm patch of wool, whose density is 291 g/m^2 (patch B)

The experiments have been reproduced with our simulator using different settings:

- three different particle grids, 11x11, 21x21 and 31x31
- two different approximations for the Kawabata diagrams (linear and piecewise linear with five segments)

For each experiment we evaluated first the accuracy of the virtual draping, computing each time the average position difference for the set of points visible on the real cloth (from 10 to 36). The results are listed for grid resolution of the virtual cloth and number of segments used to approximate the Kawabata diagrams. Then we compared the different virtual drapings. For each experiment we also present images of the real and the virtual draping.

A. *Patch A draped over a sphere (9 cm diameter)*

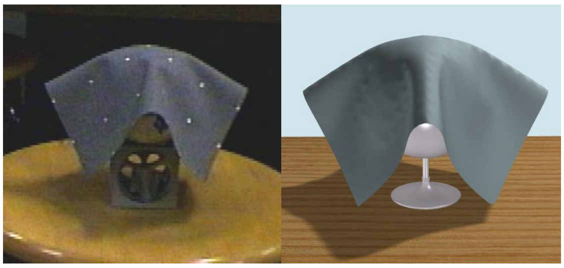
Grid size	Segments	Mean dist (mm)
21x21	5	3,37
11x11	5	9,5
21x21	1	2,33
11x11	1	9

Real Vs virtual (experiment A)

Table 1

	Mean dist (mm)
11x11: 5 seg Vs 1 seg	3,1
21x21: 5 seg Vs 1 seg	3
1 seg: 11x11 Vs 21x21	2,7
5 seg: 11x11 Vs 21x21	2,8

Virtual Vs virtual (experiment A)
Table 2



The real and the virtual draping (experiment A)
Fig. 7

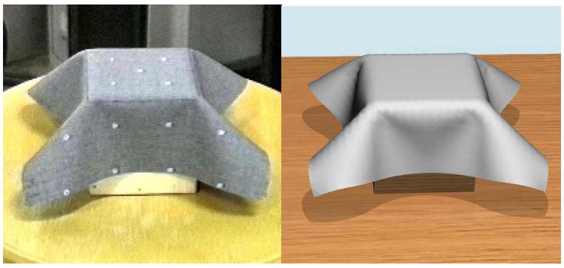
B. *Patch draped over a medium cubic block (8 cm size)*

Grid size	Segments	Mean dist (mm)
31x31	5	2,88
21x21	5	3,37
11x11	5	9,5
21x21	1	2,33
11x11	1	9

Real Vs virtual (experiment B)
Table 3

	Mean dist (mm)
11x11: 5 seg Vs 1 seg	4,8
21x21: 5 seg Vs 1 seg	4,8
1 seg: 11x11 Vs 21x21	9
5 seg: 11x11 Vs 21x21	8
5 seg: 11x11 Vs 31x31	8,5
5 seg: 21x21 Vs 31x31	4

Virtual Vs virtual (experiment B)
Table 4



The real and the virtual draping (experiment B)
Fig. 8

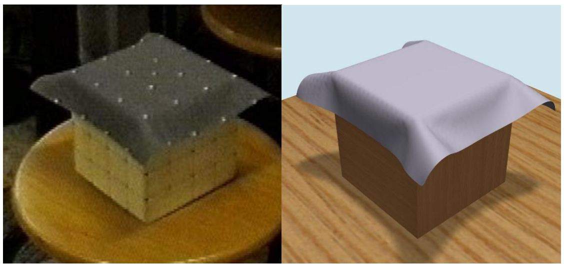
C. *Patch A draped over a large cubic block (12.8 cm size)*

Grid size	Segments	Mean dist (mm)
31x31	5	3,3
21x21	5	4,6
11x11	5	8,8
21x21	1	6,3
11x11	1	8,4

Real Vs virtual (experiment C)
Table 5

	Mean dist (mm)
11x11: 5 seg Vs 1 seg	1,57
21x21: 5 seg Vs 1 seg	2,57
1 seg: 11x11 Vs 21x21	2,8
5 seg: 11x11 Vs 21x21	3,46
5 seg: 11x11 Vs 31x31	4,03
5 seg: 21x21 Vs 31x31	1,71

Virtual Vs virtual (experiment C)
Table 6



The real and the virtual draping (experiment C)
Fig. 9

D. *Patch A hanging from two points*

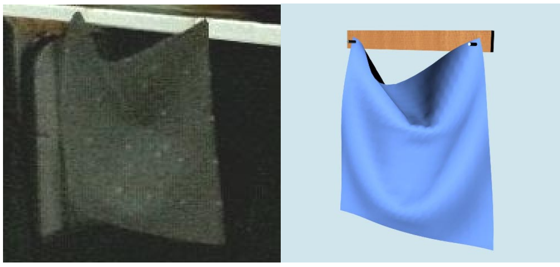
The patch A has been fixed at two points which are 15.5 cm far. Using a linear approximation of the Kawabata diagrams, the simulation reaches an equilibrium, shown in Fig. 11, which is different from the draping of the real cloth (Fig. 10).

Grid size	Segments	Mean dist (mm)
31x31	5	3,5
21x21	5	3,5
11x11	5	5,5
21x21	1	15,5
11x11	1	10,5

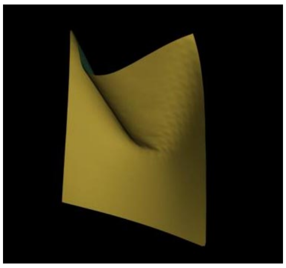
Real Vs virtual (experiment D)
Table 7

	Mean dist (mm)
11x11: 5 seg Vs 1 seg	4,6
21x21: 5 seg Vs 1 seg	6,5
1 seg: 11x11 Vs 21x21	3,8
5 seg: 11x11 Vs 21x21	4,7
5 seg: 11x11 Vs 31x31	7,6
5 seg: 21x21 Vs 31x31	1,67

Virtual Vs virtual (experiment D)
Table 8



The real and the virtual draping (experiment D)
Fig. 10



A different equilibrium
Fig. 11

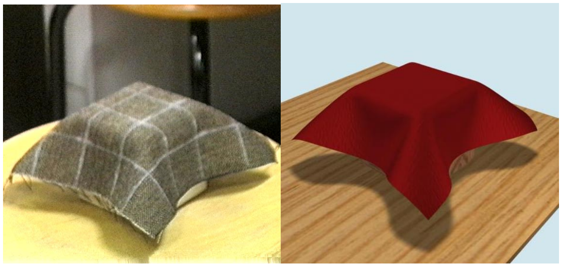
E. *Patch B draped over a medium cubic block (8 cm size)*

Grid size	Segments	Mean dist (mm)
31x31	5	3,18
21x21	5	3,4
11x11	5	5,2
21x21	1	2,65
11x11	1	5

Real Vs virtual (experiment E)
Table 9

	Mean dist (mm)
11x11: 5 seg Vs 1 seg	15,93
21x21: 5 seg Vs 1 seg	3,92
1 seg: 11x11 Vs 21x21	14,09
5 seg: 11x11 Vs 21x21	7,3
5 seg: 11x11 Vs 31x31	7,81
5 seg: 21x21 Vs 31x31	0,714

Virtual Vs virtual (experiment E)
Table 10



The real and the virtual draping (experiment E)
Fig. 12

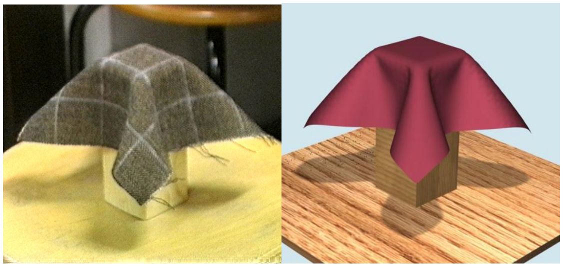
F. *Patch B draped over a small cubic block (5.5 cm size)*

Grid Size	Segments	Mean dist (mm)
31x31	5	3.3
21x21	5	3
11x11	5	10.5
21x21	1	3.5
11x11	1	8

Real Vs virtual (experiment F)
Table 11

	Mean dist (mm)
11x11: 5 seg Vs 1 seg	6.73
21x21: 5 seg Vs 1 seg	1.675
1 seg: 11x11 Vs 21x21	11.46
5 seg: 11x11 Vs 21x21	13.2
5 seg: 11x11 Vs 31x31	14.92
5 seg: 21x21 Vs 31x31	1.25

Virtual Vs virtual (experiment F)
Table 12



The real and the virtual draping (experiment F)
Fig. 13

6. RESULTS EVALUATION

The best average error obtained for the different scenarios is between 2.3 and 3.5 mm, that is almost 1.5% of the patch size. As we expected, the accuracy of the reconstruction depends largely on the resolution of the particle grid. The accuracy improves especially using a 21x21 instead of a 11x11 particle grid. It should be noted, however, that a 11x11 grid is a very coarse approximation of the real cloth. It should be also noted that using a better approximation of the Kawabata diagrams usually does not improve significantly the accuracy.

The comparisons between virtual draping show that increasing the grid resolution over 21x21 particles does not usually modify in a meaningful manner the final configuration, in spite of an increase of the computational time required.

7. CONCLUSION AND FUTURE WORK

In this paper we have presented a quantitative approach to compare the real and the virtual static draping of cloths. The virtual cloth has been modeled as a particle system. The parameters have been set, with some simplification, according to the

Kawabata diagrams. Capturing the draping of the real cloth has been made using a computer vision technique which determines the 3D position of a set of points from two or more 2D images. This technique is convenient for comparing simple draping cases, where few folds and few different equilibrium positions are possible.

Performing quantitative comparison between real and virtual draping is very important for correctly mapping the physical parameters of the cloth on the model. As far as the authors know, the technique presented is the first attempt of performing such quantitative comparison.

We have demonstrated our technique in several simple cases. Using two different kind of cloths, and different approximations of the Kawabata diagrams, we have found the average distance between the virtual and real cloth to be in the best case about 1-2% of the cloth dimensions. Some results concerning the errors due to different discretizations have been also reported.

We plan to use the technique described for an extensive investigation, covering various kind of cloths, about models and mappings of the experimental physical data, in order to understand which are more convenient for an exact simulation. We will also approach the problem of comparing “large and irregular drapings”, using global techniques, as for instance 2D transforms.

7. ACKNOWLEDGMENTS

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