An Approach to Cloth Synthesis and Visualization

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ABSTRACT

An analysis of one of the approaches to cloth modeling is carried out in this paper. The real 3D structure of the cloth at micro level is considered and the lighting simulation with the accuracy control is provided. The simulation result in BSDF form is a full description of optical properties of the cloth sample. It allows us to produce the "far view" of the cloth accurately and fast.

Keywords - Cloth modeling, yarn, fiber, woven textile visualization, ray tracing, virtual goniometrical spectrophotometer, Monte Carlo, anisotropic reflection, BSDF, BRDF.

1. INTRODUCTION

A realistic visualization of fabrics in computer graphics is important for human animation, fashion and interior design, and other fields of science and technology. Some techniques for visualization and modeling of woven materials and knitted fabrics were already proposed in computer graphics literature. Researches were mainly done in two directions:

- investigation of physical and mechanical phenomena of woven textiles (such as deformation, wrinkling and crumpling) [2, 4];
- investigation of optical properties of the cloth [1, 3, 5].

From the optical point of view the realism of an image is the result of a good correspondence of the local light scattering model applied. Some classes of objects are satisfactory described by computationally simple non-physically-based local illumination models widely used in computer graphics. As for materials with more complex optical properties, such as cloth, anisotropic paint, dusty surfaces, skin, leaves etc., the standard methods seem to be inappropriate for the realistic appearance visualization. To find a suitable physically-based model for woven textiles we concentrate on the cloth structure.

First of all we investigated the cloth patterns with a scanning electronic microscope. Considering the cloth structure in details we come to explicit model where straight fiber segments are represented by geometrical primitives that belong to some repetitive cloth element called micro-element (rapport). It differs from the other approaches, for example one proposed in [1], because parameters of real cloth structure are considered during the modeling. The optical characteristics of a micro-element describe average properties of the cloth in a point. Observing the cloth from distance we see the true picture.

For qualitative rendering it is sufficient to compute BSDF (Bi-directional Scattering Distribution Function): $\rho_{bd}(\theta_i,\phi_i,\theta_r,\phi_r) : S_i^2 \times S_r^2 \mapsto \Re$ for cloth micro-element, where :

S_i^2 is the unit semi-sphere, S_r^2 is the unit sphere;

θ_i,ϕ_i - the elevation and azimuth angles of incidence;

θ_r,ϕ_r - the elevation and azimuth angles of reflection / transmission.

This BSDF determines optical properties of a cloth point in full. It is natural to subdivide the process of cloth rendering into two steps. At first $\rho_{bd}(\theta_i,\phi_i,\theta_r,\phi_r)$ is computed for a cloth micro-element. Virtual goniometric spectrophotometer based on Forward Monte Carlo Ray Tracing was developed for it. Then any object with assigned BSDF can be rendered by means of appropriate computer graphics software. For this purpose we used **Specter** 5.10 system distributed by Integra, Inc. (http://www.integra.co.jp).

In the next section we give a brief introduction with a cloth object structure and some basic terms that are necessary for its specification. Section 2 describes the explicit model for representation of woven fabrics at micro level. The BSDF calculation by means of virtual goniometric spectrophotometer is explained in Section 3. The results of applying the explicit model to the silk samples are presented in Section 4. The original color counterparts for the images used in this paper and additional images in color fringe technique can be found in HTML version available on http://rmp.kiam1.rssi.ru.

2. CLOTH STRUCTURE

As it is known textiles are made up of yarns. Every yarn consists of elementary fibers. Yarns can be combined in different ways and that causes a variety of textile structures. There are two basic cloth structures stemming from the process of its manufacturing: woven and knitted fabrics. In the knitwear all yarns are oriented in the same direction. This paper concerns woven materials.

In woven fabrics yarns are oriented in two mutually orthogonal directions. Longitudinal (warp) and transverse (weft) yarns can be interlaced in many ways and have different thickness and density. They form smooth or rough surface on the right side of the cloth and are more or less filled with fibrous material. Each yarn consists of several micro-fibers and they can twist around the yarn axis. In particular case it can be parallel bunch of micro-fibers (Fig. 1a). The more complicated model is in the cloth sample in Fig. 1b.

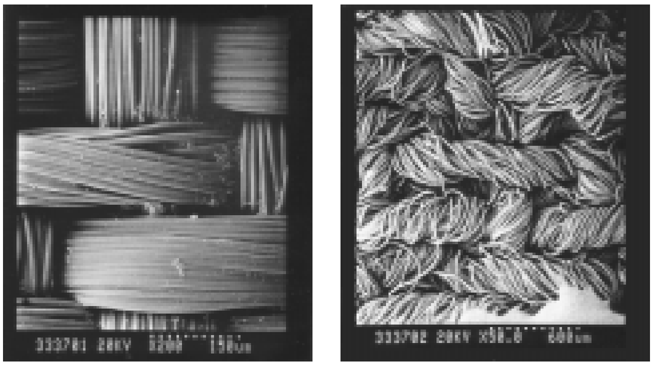

Fig.1(a),(b). Woven textiles received via scanning electronic microscope Hitachi S800.

So the main characteristics of woven fabrics are thickness and structure of yarns, a kind of interlacement, a density, and several geometric parameters. The cloth structure influences its appearance and properties.

The most cloth simulation algorithms are based on supposition that any woven object has regular and periodic structure specified by micro-element [1, 3, 5]. It can be defined by interlacing matrix. For example, interlacing structure and matrix for the cloth sample in Fig. 1a will look something like this:

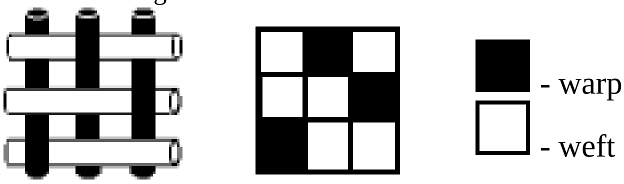

Fig.2. Interlacing structure and matrix.

As for optical properties we suppose that fibers are typical dielectrics and the radiance reflected from and transmitted through a fiber boundary is given by the classic Fresnel's equations. A fiber is translucent, and it reflects light and refracts it as well. Its behavior is determined by the refraction index, the reflection and the transmission in every wavelength band per unit length (i.e. surface and volume absorption).

3. EXPLICIT CLOTH MODEL

We investigate an explicit approach to cloth modeling. Its principal peculiarity is an accurate model representation at the level of micro-element.

A micro-element representation consists of fibers approximated by the sets of primitives of the same type: infinite cylinder bounded by two planes. The primitives represent a fiber are placed along a curve line which is a fiber axis that in turn is a winding curve around the yarn axis.

We assume that a yarn axis (say a warp one) consists of several pieces which are segments of either circle or line. All circles have centers that coincide with the centers of weft yarn cut. Radius of every circle is radius of warp yarn plus radius of weft yarn.

The composition of fibers inside of the yarn is specified in the initial yarn cross-section. An arbitrary yarn cross-section is calculated by a rotation of the initial one. We provide two kinds of cross-sections of yarns: circular in case of twisted fibers and elliptic otherwise, i.e. when all fibers are parallel to the yarn axis. The pictures below show circular (Fig. 3a) and elliptic (Fig. 3b) cross-sections of several yarns.

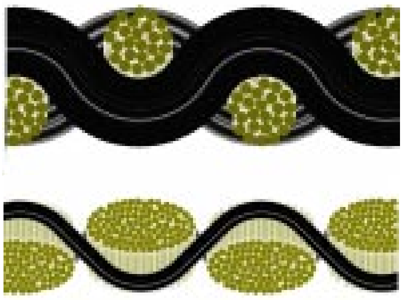

Fig. 3(a),(b). The cross-sections for the explicit cloth model.

4. RAY TRACING

The general ray tracing technique was applied to cloth BSDF synthesis as well as to cloth visualization in TBT. The similar approach was described in [6].

Ray tracing provides a base for BSDF calculation by virtual goniometric spectrophotometer (VGSP). VGSP uses Monte Carlo approach which in principle does not impose any restrictions on the complexity of light propagation in the simulated cloth. Below is a rough idea of the method.

The directions of initial light rays are chosen in accordance with uniform 2D grid of incoming light distribution. Their target points are randomly generated in the original area of cloth micro-element. These rays are traced through the scene deciding the next ray direction probabilistically in accordance with Fresnel’s law after each scattering event. After several events each ray will go out from the micro-element or will be absorbed. The result BSDF is a contribution of outcoming rays (θ_r, ϕ_r) with respect to corresponding incoming rays (θ_i, ϕ_i).

This method should provide, in principle, unlimited accuracy of the calculation with account for arbitrarily complex interreflections. An important advantage of Monte Carlo method is its easy accuracy control. VGSP provides the direct accuracy control. There is only one user-controlled parameter that determines accuracy: acceptable average error of luminous intensity distribution of outcoming light. Furthermore, VGSP reports current accuracy achieved after each increment of calculation. The accuracy measures an RMS deviation of calculated BSDF from some "ideal" one. We use the term "ideal BSDF" to denote in some sense the best BSDF on the given mesh.

The important problem is boundary cases. When during the ray tracing a ray abandons the cloth micro-element via its side faces, it enters another micro-element. As we have only one micro-element in full, we have to decide what to do with such rays. The simple solution proposed in [3] is to provide a "continued" ray tracing: whenever a ray leaves one of the side faces of the micro-element, it has to be reset cyclically to the corresponding opposite face. This approach is not ideal: it requests some conditions for fiber location that can contradict with original micro-element specifications received from manufactures.

Another solution of this problem we found is to extend micro-element in both directions for some length to support geometry duplication. The extension length depends on a number of parameters and is determined for each cloth pattern experimentally.

The explicit model for the cloth we used has a deficiency in a form of fiber collisions. The fibers of different yarns can interlace with each other very closely that causes fiber intersections which in turn can lead to incorrect light propagation model.

Because it is difficult to provide a 100% robust collision detection algorithm we assume that fibers can be slightly intersected. It should be treated not as a fiber intersection but as a small error in a fiber location. It is supported in the following way. If the ray origin was inside a fiber then only an intersection with this fiber surface is checked. If a ray which leaves the fiber appears inside another fiber then the ray is shifted back to the surface of the second fiber and the entrance into this fiber is processed.

The ray tracing technique is quite standard: to find all intersections of a ray with all fibers (several intersections with a single fiber are possible) and to choose a nearest one. This however was dramatically accelerated by using of the uniform voxelization.

5. RESULTS AND IMAGES

We have created the explicit models for the real cloth samples that are artificial silk. The next step was the synthesis of BSDF for them with the aid of VGSP under the accuracy control. It is the most time consuming phase.

The calculation of 4D BSDF in full with good accuracy can take up to tens of hours slightly depending on cloth sample parameters. The calculation of reduced BSDF, for example 2D BSDF for fixed incidence angles, is of course much faster. The reduced BSDFs were computed to create the charts below.

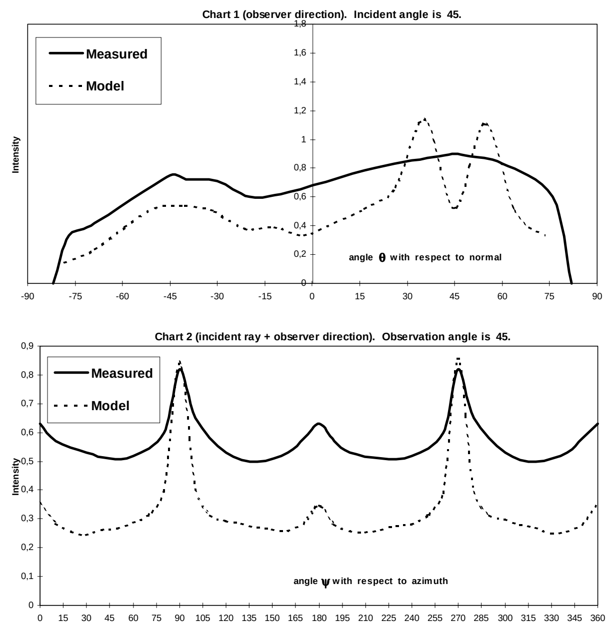

Fig. 4(a),(b). The comparison of measured and calculated data.

We have calculated luminance charts for the explicit cloth model and compared them with the measurements made for the same cloth sample, where:

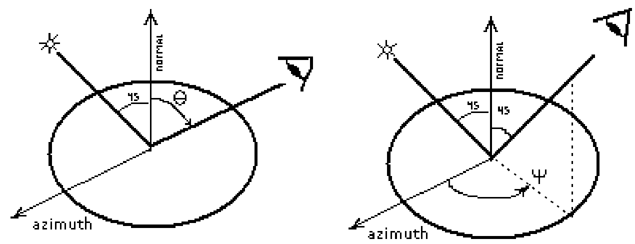

Fig. 5. The measure schemes for chart 1 and chart 2.

The general conclusion is that there is not a one-to-one correspondence between measured and calculated charts but the most of the measured chart features are reflected properly. The most noticeable differences are high peaks on the plots of calculated data.

Finally we assign 4D BSDFs to the appropriate 3D models in order to perform the rendering under arbitrary light conditions and a camera setting. The resulting pictures exhibit the expected visual effects produced by the silk patterns in the form of anisotropic highlights. Figure 6 at the end of this paper shows the cloth appearance for different patterns.

6. CONCLUSIONS AND FUTURE WORK

In general, the explicit model is quite appropriate for the visualization of such cloth materials as artificial silk. It seems to be a very promising design tool for textile engineering as it is based only on cloth pattern parameters available from cloth manufacturers such as interlacing structure, detail specification of yarn form etc.

The one of averaged features of the created explicit model is the distribution of primitives along their orientation. It strongly affects reflection properties of the cloth. In the current model this distribution includes two delta-functions (correspond to line segments) with constant segment between them (corresponds to arcs). This specific distribution form can be considered as a reason of the difference between measured and calculated data found in Section 4.

On the other side, as we can see in Fig. 1(a) and especially in Fig. 1(b) some stochastic fiber deviations are peculiar to cloth model in the reality. Stated more precisely, the cloth structure represents both deterministic and statistical elements. Deterministic elements are interlacing structure, color of yarns, a number of fibers in a yarn, fiber cross-section shape etc. Most significant statistical elements are fiber distribution along the yarn axis and roughness of the fiber surface.

We intend to enhance the explicit model by a statistical approach to take into account stochastic features of the cloth. Furthermore we intend to apply our results in woven textile visualization to the knitwear to provide “far view” of any kind of clothes.

Finally we will provide the more comprehensive comparison of calculated images with real photos.

7. ACKNOWLEDGEMENTS

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Синтез и визуализация ткани. Метод явного представления

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В статье анализируется один из подходов к моделированию ткани. Трехмерная структура ткани рассматривается на микро уровне и обеспечивается расчет освещенности с произвольной заданной точностью. Результат моделирования в форме BSDF полностью описывает оптические свойства образца ткани. Этот подход позволяет визуализировать ткань на некотором, по отношению к пользователю, расстоянии физически аккуратно и быстро.

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