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Challenges in Appearance Capture and Predictive Modeling of Textile Materials

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Abstract

The appearance of cloth is the result of complex light interactions within the structures present in textile materials, particularly challenging due to their multi-scale nature. In addition to the inherent complexity of cloth rendering, there is a lack of connection between computer graphics techniques and manufacturing processes followed in industry. We discuss existing techniques and pose questions about which are the right paths to follow for a better synergy between CG and textile research, including (but not restricted to): defining a standard set of properties required to predict the appearance of cloth to be manufactured; developing both acquisition techniques reliable and suitable for industrial processes and other frameworks more focused on inexpensive capturing (e.g. based on single pictures, Pantone labels); finding material representations that are robust in absence of several low-level parameters; creating a standard for color depth depending on the dye type and dying technique; developing a standard to account for post-process steps (washing, chemical treatments, etc) on the mechanical and optical properties of the textiles.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Line and curve generation

1. Introduction

Depicting realistic fabrics in important not only for computer graphics but also for textile industry. However, rendering cloth remains very challenging due to the multi-scale nature of textiles and the complex light scattering patterns exhibited by the fibers that form each individual yarn. Thus, accounting for both geometric details and light scattering at very small scales (microns) is needed to retain the overall look of the garment at longer distances.

Much effort has been done in the last few years to obtain realistic renderings of cloth (see Figure 1), all by reaching the scale of the fibers, either by procedurally modelling them [SKZ11] or through Computed Tomography Scanners (CT) captures [ZJMB11, KSZ*15, ZLB16]. Another interesting approach [SZK15] reproduces the appearance of small pieces of cloth by using macro-photographs to estimate fiber, yarn, and pattern parameters. These works are commonly centered in the geometry of the fibers and yarns, adopting several severe simplifications for the scattering from fibers. Furthermore, they lack the actual fabrication parameters used when physically manufacturing the cloth, limiting their applicability to predictive rendering.

In previous work Aliaga et al. [ACG*17] present a first step towards a model specified by the actual fabrication parameters used by fiber makers, focused on high-quality scattering functions accounting for real-world properties of cloth fibers, from a ray-optics perspective .

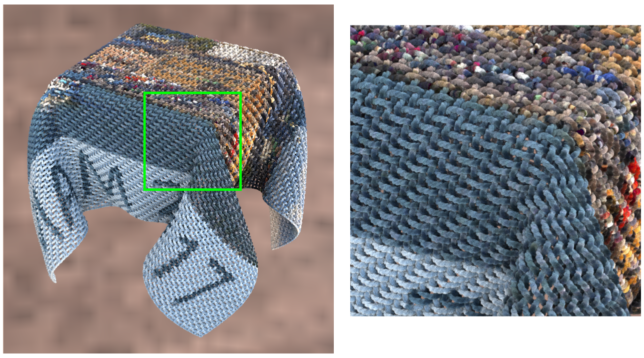

Figure 1: *Fabric colored with spatially varying dyes. Simulations are performed at the yarn level over a twill weaving pattern of 2-ply yarns. Although computer graphics techniques allow very realistic an plausible renderings of cloth, this paper discusses how to bridge the gaps between CG and real-world manufacturing processes.*

On the following sections, we will present the existing approaches and their limitations from a computer graphics perspective, and discuss which should be the paths to follow when reproducing the appearance of cloth, for practical and direct application to manufacturing processes.

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2. Existing Techniques

One of the first and biggest problems in cloth rendering is the great heterogeneity of the representations used to define the geometry and the scattering models. Many pipelines in CG production are still based in planar representations of cloth, namely triangular meshes resulting from dynamics simulation, with a stack of shaders and textures manually tweaked by artists. There are other more sophisticated planar representations like bidirectional texture functions (BTFs) or parametric local scattering models [SBdDJ13], but they are costly in storage for certain types of cloths, among other problems (self-masking, parallax, lack of silhouettes, etc). For more details we refer to the original papers, or the survey by Schröder and colleagues [SZZ12].

Volumetric cloth modeling There exists two main volumetric approaches: 1) treating cloth as an heterogeneous anisotropic volume [JAM*10] and using volumetric path tracing for rendering, and 2) explicitly modeling each fiber or yarn, similar to hair rendering techniques. Zhao and colleagues [ZJMB11] followed the former approach, using Micro-CT scanners of cloth to obtain volumes at micron resolution. While CT-based models allow for high-quality renders of cloth, they rely in complex and expensive capturing setups, and manual intervention or optimization [KSZ*15] with respect to a target cloth appearance is needed to define the optical parameters of cloth garments.

Instead of relying on captured data, Schröder and colleagues [SKZ11] procedurally generate cloth garments as a collection of individual yarns, transformed into a volumetric representation using Gaussian distributions of fiber orientation and density. Their method even simulates small fly-out fibers (hairiness) and allows predictive reverse engineering of real cloth [SZK15]. Zhao et al. [ZLB16] automated the fitting of such yarn procedural models from measured data.

Scattering models Most previous approaches have assumed general scattering models for fibers, ranging from microflakes [JAM*10, HDCD15] for volumetric models, to explicit fiber scattering models similar to hair rendering e.g. [MJC*03, YTJR15]. While microflakes can prroduce realistic and plausible results [ZJMB11], it has been shown that fiber scattering models are more suitable to match the appearance of real-world cloth [KSZ*15].In this context, Schröder and colleagues [SKZ11, SZK15] use the parametric BCSDF model proposed by Zinke and Weber [ZW07]. Khungurn et al. [KSZ*15], on the other hand, proposed a simple and expressive fiber-based model suitable for both rendering and appearance capture of real garments. A common limitation of all these previous models is their assumptions about real cloth fibers, like the elliptical cross section, and the disconnection to fabrication parameters; Aliaga et al. [ACG*17] represent a first step towards this direction.

Textile Research Several works in textile research have used simulation to predict the appearance of cloth. Most of these works use light simulation in yarns or fibers focusing on quality assessment of specific features such as luster [TMM09, AYMT03], and on determining the optical properties of cloth by means of inverse rendering [HSEMN09, RGS10]. There are also works that perform simulations to predict the appearance of fibers scattering [Yam02, LW12], or study the effect of textile properties in the macroscopic appearance of cloth (e.g. propagation of polarized light) [GHR97, MH99, PDW12]

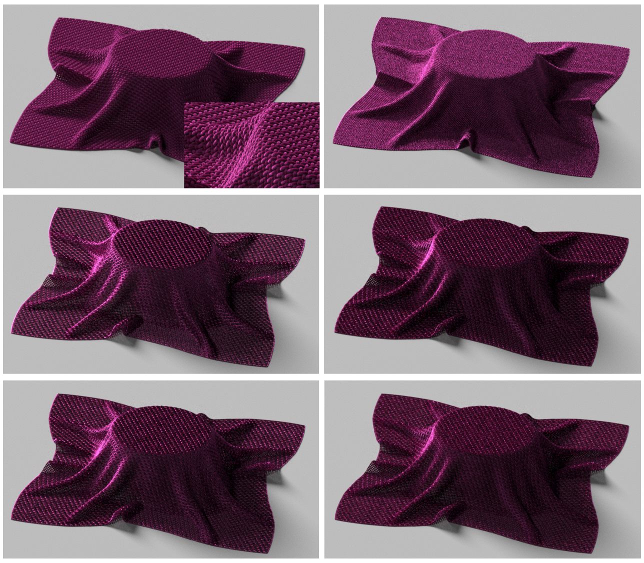

Figure 2: *Weaving patterns, fiber type and yarn twist-sense, greatly affect the overall appearance of cloth. Top row, from left to right: cotton twill, polyester plain. Middle row, left-right twist (Z2S) and same sense at perpendicular yarns. Bottom row, from left to right: polyester satin with increasing levels of fibers twisting (6 to 12 twists per inch, more diffuse).*

3. Open Problems and Possible Solutions

Cloth Structure and Manufacturing Processes The manufacturing process is composed by, at least, four stages: yarn production, weaving/knitting, garment creation (pattern, cutting and sewing), and post-process finishing. Due to the inherent multi-scale structure and composition of the cloth, there are infinite ways to form yarns, with different i.e. fiber twisting, warp-weft tension, techniques for attaching plys, patterns of weave, knit, lace, etc. These parameters affect both the mechanical and optical properties of the garment (see Figure 2) and are described in detail at the **technical sheet**. This sheet is available both for cloth designers and textile engineers. Unfortunately it is usually incomplete or practically nonexistent, because the manufacturing processes are executed by different agents, with no motivation to propagate information through the production chain other than what it should be included in the final labeling of the garment. For instance, at the garment design step, barely fiber composition (in percentages) and textile weight (grams/dtex) are known.

The communication between agents is also highly inefficient: something as simple as color has to be defined in terms of CYMK printouts without calibration, making the Pantone scale one of the most accurate references used. As a result, hundreds of thousands of actual samples are being sent just for a single collection each six months. The process is thus difficult to track bottom-up, for in-

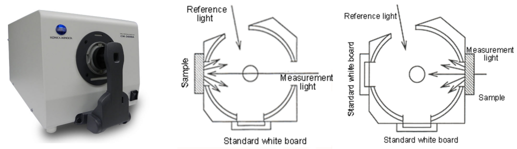

Figure 3: *Left: Spectophotometer for 16 to 31 samples in UV and visible spectrum. Middle: Scheme for diffuse reflection capture. It can also capture direct specular reflection at 8 degrees. Right: Scheme for transmittance capture.*

stance dyeing has several chemical options (cationic, reactive, vat, mordant, natural, etc.) but it can also be applied to the yarn, the woven fabric or even the whole garment. Moreover, the finishing steps alter the appearance by introducing chemical treatments to the overall cloth or fabric: from factory washing and bleaching to laser weathering, or even subtle side effects from mechanical improvements such as silicon spraying over the surface to increase roughness and hence friction (for increased resistance against seam failure).

Therefore there is a necessity to study the effect of each process on the textile from known parameters, tabulating and fitting curves to modulate the parameters which can be captured and stored in a digital library.

Parameter Mapping Rendering parameters are barely related to real physical data used by industrial manufacturers [BH08]. For instance, reflectance is not measured directionally, but rather by means of sphere integration (see Figure 3) where a diffuse and plus a near-zero degrees reflection are acquired. The textile samples are folded to the point that there is no scattering from the background and the number of folds are set on a case-by-cases basis. Although diffuse transmittance can also be acquired, it is not usually measured unless the manufacturer wishes to test specific cases: UV transmittance, shading degree (e.g.:umbrella), etc.

These parameters are far less accurate than BCSDFs or diffusion profiles, and they are not usually available: it is a process only used for comparison purposes on quality control or as requirement for auctions and massive sales of textile products. When customers specify color responses, controlled lighting systems such as Spectralight® from X-Rite® are used for quality control under different lighting sources (daylight, cool fluorescent, incandescent, etc.).

If yarn manufacturing data is available, such as Depth of Shade (DoS), the percentage of cloth weight in pure dye powder, we can infer the BCSDF [ACG*17] and predict its appearance (e.g.: a 3% will be a very deep and intense color).

Moreover, perceptually-based features are used in the design space at a very high level, usually connecting several physical properties known only by textile engineers. For instance *luster* is defined as sheen or quality of shining by reflecting light and it can be affected by fiber cross section (cotton less than mercerized cotton), yarn twists per inch (the lower the shinier), the weaving pattern (e.g.: *satin* has longer crossings) but even a small detail such as yarn twist orientation in both warp and weft (Z or S) has a great effect in appearance due to the alignment of the reflection cones from perpendicular yarns (see Figure 2).

From a rendering perspective, there are multiple approaches to represent cloth: from heteregenous media based on distributions of oriented microflakes that require density, orientation and a single scattering coefficient to SGGX distributions which represent the particles as ellipsoids defined by three-axis projections and allow for level of detail interpolation. A stochastic procedural geometric model can easily map many physical parameters obtained statistically from actual samples (average fly out fibers per cm, fiber distribution function, etc.) to heterogeneous media representations. However the later are not accurate at close range, as fiber density might be very low, and fiber refraction is not explicitly modeled. A global solution could be to integrate explicit path tracing for high-frequency details and volumetric rendering and diffusion for higher-order scattering, as shown by Meng et al. [MPH*15] but for structured repeating patterns.

Acquisition Techniques As we have seen, a bottom-up approach is unfeasible, and as such, we will have to combine it with top-down optimization by inverse simulation from incomplete input data such as average diffuse spectral reflection, Pantone colors, or even uncalibrated photographs.

We propose to rely on a database of common textiles completely characterized for both manufacturing and rendering parameters. Input data will be completed with initial guesses (both geometric and statistical models) from the database and then optimized in an iterative fashion, fitting the missing parameters. In the literature we have examples which rely on expensive acquisition devices (CT scanners) and costly image-based optimizations to fit real cloth samples that require dozens of parameters as input. The reverse engineering approach of Schroeder and colleagues [SKZ11] represents a first step in the direction of affordable acquisition procedures, but lies still far in terms of physically-based parameters directly linked to textile industry.

Given the cost of centralizing the acquisition of textile samples, a desirable feature for the industry would be the use of inexpensive capturing techniques based on: single pictures, controlled lighting (including UV-A for optical brightening agents-OBAs), or Pantone labels and available technical data [ZLB16]. The outcome would be statistical procedural models obtained by means of a combination of technical sheet data, library examples and computer vision techniques.

4. Conclusions

In this paper we have introduced the problem of textile characterization in a rendering context. Although we have previously shown promising results for physically-based cloth rendering with bottom-up factory parameters, we have also identified that it is not realistic to assume that fabrication data is available ant any point of the process. Multiple agents are involved with partial information and little access to calibrated measuring devices. A solution to bridge the gaps in the garment industry, likely involves the definition of a digital technical sheet which will be progressively built through a combination of bottom-up optical simulation and top-bottom parameter fitting by inverse rendering.

Although there are compelling models for aggregated fibers and yarns as volumetric hetereogeneous media (microflakes, SGGX, etc), and explicit geometry at the fiber level (BCSDF), there is no clear model for seamless transition from small to large scale and level of detail filtering. We believe that the work by Meng et al. [MPH*15] could be a basis for future research with structured geometries such as cloth.

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