THE SIMULATION OF CLOTH USING ACCURATE PHYSICAL PARAMETERS

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ABSTRACT
Cloth simulation and fabric measurement are tightly linked areas of research. In order to obtain high quality animations of dressed models, the properties of the simulated garment must first be evaluated in an accurate and adapted way. As cloth is a very complex, anisotropic material, the evaluation of its properties is difficult to achieve, and various approaches exist. The outputted parameters have also to match the required inputs of the simulation engine. Until today, simulation systems have evolved to such a level that we are able to not only simulate simplified, static clothes, but also complex dynamically moving garments, in the time frame, expected by the clothing industry. This evolution brought new challenges for fabric characterisation methods as well and now the fabric measurement methods and derivation of fabric parameters also have to be pushed forward. The possible accuracy of virtual garment simulations is demonstrated on the basis of the example “high fashion in equation”.

KEY WORDS
Fabric measurement, cloth simulation, computer animation

1. Introduction

Fabrics are complex visco-elastic materials. They must have sufficient strength and at the same time they have to be flexible, elastic and easy to pleat and shape. Their simulation is not easy, as their behaviour is difficult to describe and predict. Nevertheless, computation algorithms have been developed over many years and evolved to such a level so that today we are able to not only simulate simplified, static clothes, but also complex dynamically moving garments [1]. But, not only advanced computational models are responsible for precise virtual garment simulations. Also exact input parameters play an important role for a correct reproduction of the fabrics mechanical behaviour. For instance, newly-developed computation systems finally allow the simulation of the non-linear fabric behaviour; but in order to truly reflect these characteristics in the virtual computation, we have to be able first of all to measure them appropriately. Experimental values for the main mechanical and physical parameters can be derived from standard fabric characterization experiments such as the “Kawabata Evaluation System for fabrics” (KES-f) [2] and the “Fabric Assurance by simple Testing” (FAST) [3]. A more recent measurement method, which applies similar principles, is the FAMOUS system [4]. However, all existing characterization methods have not been designed for the purpose of deriving parameters for virtual simulations thus special care must be taken when applying the obtained parameters to a dynamic simulation.

2. Mechanical properties of cloth

Regarding mechanics, the behaviour of a textile material is influenced by four main factors: the fibre origin, the yarn structure, planar structure as well as possible applied finishing treatments. These components allow the creation of a vast variety of textiles, which responds to the high demands of the apparel industry.

- Raw material: Fibres can be either obtained from natural resources or they can be man-made. Natural fibres are distinguished between vegetable and animal fibres, whereas the vegetable fibres are less elastic than animal fibres. In opposition to natural fibres, it is impossible to generally classify man-made fibres regarding their mechanical properties, as they are designed products. Completely new fabric characteristics appeared with the invention of synthetics, such as nylon and elastane [5].

- Yarn structure: Yarns are twisted fibres and filaments, where the degree of twist influences the yarn stiffness. A high twist is responsible for a greater bending stiffness. In plied yarns, i.e. two or more single yarns twisted together, the stiffness is increased compared to single yarns. Filament yarns with greater apparent volume due to physical, chemical or heat treatments are named textured yarn. Textured yarns are generally softer.

- Planar structure: The way of crossing threads into a planar surface can be made by means of weaving, knitting or bonding. In general we can say that woven or knitted structures are usually more firm than the same material out of the non-processed source material. Woven textiles are stiffer than knitted and the type of crossing the threads and the yarn density affect the mechanical properties.

- Finishing treatments: Finishing is an extremely complex subject because of the large number of changes that can occur to a fabric. It can completely change the mechanical characteristic of a fabric, what makes it difficult to predict a fabric's behaviour from its components. Finishing treatments can be applied on the fibres, yarns or textiles.

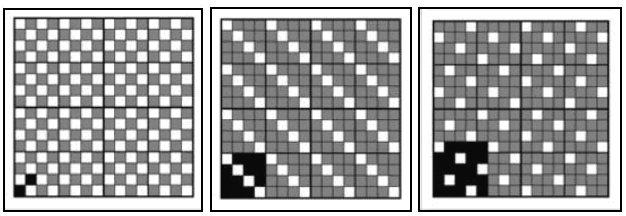

Figure 1 scheme plain weave, twill and satin weave

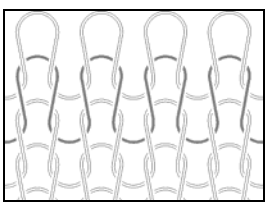

Figure 2 scheme weft knit

In State of the Art computation systems, mechanical properties of deformable surfaces are grouped into four main families:

- **Elasticity:** which characterizes the internal forces resulting from a given geometrical deformation.

- **Viscosity:** which includes the internal forces resulting from a given deformation speed.

- **Plasticity:** which describes how the properties evolve according to the deformation history.

- **Resilience:** which defines the limits at which the structure will break.

Most important are the elasticity properties such as tensile, shear and bending as they are mainly responsible for the mechanical effects and the evaluation of a garment. Time related parameters become important input parameters for dynamic garment simulations.
Depending on the amplitude of the mechanical phenomena under study, the curves expressing mechanical properties exhibit shapes of varying complexity. If the amplitude is small enough, these shapes may be approximated by straight lines.
For an accurate dynamic garment simulation, parameters must be extracted from real fabric measurements. This isn't a simple task to perform because fabric is a very complex material, which has an isotropic behaviour. Thus special care must be taken when performing the measurements and applying them to a virtual simulation.

3. Real world fabrics

3.1 Measurement of fabric properties

Each textile possesses typical characteristics, which are advantageous for some types of garments, but can be unfavourable for others, regarding garment comfort. Evaluating fabric properties isn't trivial thus various evaluation means were proposed. The simplest one, and still widely used is the "fabric hand" concept [6]. It consists of touching, squeezing and rubbing the fabric in one's hand to evaluate its properties. This is a subjective measurement which cannot be used for the purpose of virtual simulations. Objective fabric characterization methods measure and relate the major mechanical properties, in order to obtain comparable information about textiles. The applied physical tests analyse and reflect the sensations felt during the subjective fabric assessment and describe them with a numerical value [6]. Important fabric properties are flexibility, compressibility, elasticity, resilience, density, surface contour (roughness, smoothness), surface friction and thermal attributes, which are the result of a broad fundamental research on fabric properties [8][9]. In virtual simulations, the main imitated mechanical properties are elasticity, shear, bending, density, weight, thickness and friction. The KES-f system was developed in the 1970's by Kawabata and constituted the first standardization of objective fabric assessments. Since, this method is widely used for the objective characterization of fabrics, as well as for studies of fabric mechanical properties. In the late 1980´s the CSIRO Association in Australia realized the importance of a commercial measurement for wool fabrics and tried to offer a simpler and cheaper alternative to KES-f, the FAST method. Both, KES-f and FAST measure the same parameters; however different measurement principles are applied. The FAST method uses simpler procedures than KES-f and permits only a linear interpretation of the measured data, whereas KES-f provides a complete stress-strain profile for all measured characteristics. The measurements of both systems are conducted in the low force area, what corresponds to loads which a fabric is likely to undergo during garment manufacturing. Alternative, more flexible measurement devices exist for the measurement of tensile and hysteresis properties.

Elasticity tests are designed in a way to return the correlation between applied forces and corresponding fabric elongations. The FAST method measures the elasticity property at one load of 100 N/m along warp and

weft direction. KES-f tests the tensile behaviour with an increasing force of up to 500 N/m also along weft and warp direction. After the tensile load attains the maximum force, the recovery process is recorded.
During shear tests, the required forces to change the angle between the orthogonal intersecting threads of textiles to certain extend are assessed. Whereas the tensile property is more influenced by the fabrics fibre composition and the yarn structure, the shear characteristic is mainly influenced by the fabric structure. Different measurement principles can be applied. The main standard method fixes the fabric between two clamps and applies opposite forces until a maximum angle (KES-f [2]) or maximum force is attaint. Other methods measure the fabrics extension-compression in the bias direction (FAST [3]) [10].

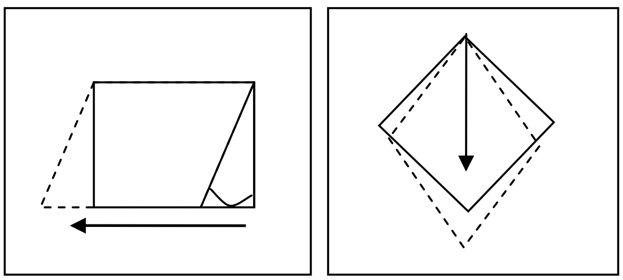

Figure 3 Angle-force method (left) extension in bias direction (right)

Regarding fabric bending tests, there are two main categories. The first category measures the bending deformation under the fabrics own weight. The most well known method within this category is the Cantilever test, which uses the engineering principles of beam theory. A fabric is moved forward to project as a cantilever from a horizontal platform. As soon as the leading edge of the fabric reaches an angle of 41.5° to the horizontal platform the bending length is measured (FAST). Another method of this category consists in the folded loop method, where the fabric is fold back on itself and the height of the loop measured. The second category of bending tests is designed to return the moment-curvature relationship by measuring forces or moments (KES-f). Therefore, a fabric is fixed between two clamps and bent in an arc of constant curvature, where the curvature changes continuously and applied moments recorded.

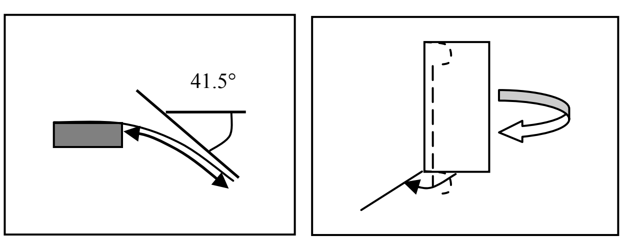

Figure 4 Cantilever method (FAST) and Moment-curvature method (KES-f)

In contrast to elasticity, shear and bending, the friction property is not an internal but external mechanical force, varying with each other contact material. Distinctions are made between static and dynamic friction. The static friction is related to the initial force, what is needed to overcome to start moving a material against another object or surface. The dynamic friction however occurs during the movement itself and is therefore generally lower than the initial static friction. There are several methods to assess friction. Within the standard fabric characterization experiments (KES-f), the friction is measured by moving a piano-wire over the fabric at a constant force frequency. Friction is not measured by the FAST system.

3.2 Mapping to Computational Models

For the actual derivation of fabric input parameters, a mathematical description of the measured data is needed. Depending on the complexity of the implemented computational model and the available amount of measured data, this mathematical interpretation can be linear (from FAST) or non-linear (from KES-f and alternative devices).
The tensile behaviour of fabrics is strongly non-linear for most textiles. Strain-stress profiles of very elastic materials are particularly characterized by a curved envelope. Versatile computational models are able to simulate the nonlinear tensile behaviour and therefore ask for an adequate input data. Linear parameters derived from the measurement data from FAST, are correct in the low force area, occurring for example during static simulations, where the fabric is basically stressed by its own weight. However, linear parameters are incorrect for the simulation of higher stresses, as referring to them much lower loads are sufficient to achieve larger fabric elongations. Moreover, used in virtual garment fitting processes, linear parameters return a wrong feedback about the garment comfort (Figure 4).

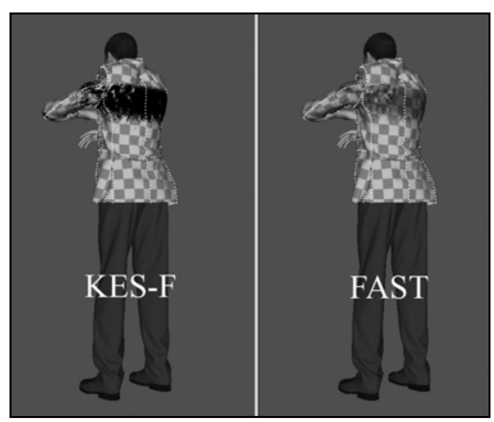

Figure 5 Simulations using KES-F and FAST parameters

At a first glance, the non-linear fabric parameters derived from the KES-f strain-stress envelopes seam to be better suited for the derivation of nonlinear tensile parameters. However the KES-f method is limited as well, as it returns the strain-stress profile only up to one maximum load. Dynamic cloth simulation is a much more complex issue. When the garment follows the movement of the mannequin, the fabric undergoes not only one but many deformations and relaxations of various low and high loads in different temporal distances. For that reason, derived parameters from KES-f are accurate for the one specific measured force (500 N/m), but not for various loads. Hence, for dynamic simulations, multiple load/unload experiments with different applied forces, which reflect what actually happens during the wear of a garment, are needed. Also, aspects which are related to the simulation history such as plasticity and properties which are time related such as viscosity, become important input characteristics for dynamic garment simulations. Until today, the viscosity of textiles is a little investigated field of research and no standard measurement exists for the characterization.

Depending on the type of fabric material, the fabrics shear behaviour varies from towards linear to non-linear. State of the art simulation systems use a nonlinear shear computation model. Therefore, depending on the fabric material, a linear or nonlinear mathematical description is needed (Figure 5).

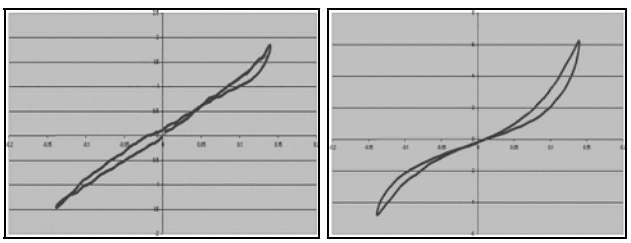

Figure 6 Linear and nonlinear shear strain-stress behaviour

Similar to the tensile property, the nonlinearity of the shear behaviour can be more accurately derived from complete strain-stress envelopes, whereas the more linear shear comportment can be accurately interpreted from single measured forces as well. However, in contrast to the tensile property, the error in the comfort feedback for simplified nonlinear parameter is smaller. This is related to the fact that regarding shear, generally lower forces are concerned.

Even in versatile computation system, the complex bending property is still linear modelled. Thus, a simple (linear) mathematical interpretation for the bending behaviour is precise enough. The bending rigidity is returned by standard measurement methods as characteristic value. As this measure is a description of the slope between two major points of the measured data, it is suited to be directly taken as linear bending characteristic. The comparison of the bending rigidity obtained from the FAST and the KES-f measurement systems shows a good correlation for the bending rigidity value (Figure 6).

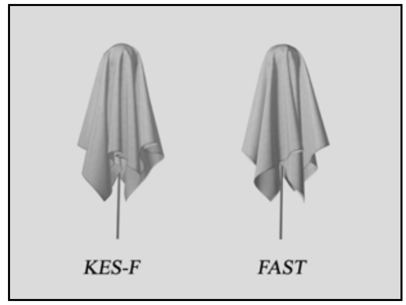

Figure 7 Virtual Fabric drapes using KES-f and FAST parameters

3.3 Multi-Layered Fabrics and Seams

Regarding complete garments, not only the fabric characteristics are important for a mechanical accuracy and a good visual appearance. Additional clothing aspects, such as seams, interlinings and fabric fusing become important influencing factors for virtual computations and demand a separate examination.

Figure 8 Fitting and simulation of a complete garment

3.3.1 Seams

Conventional garments are generally not composed out of only one, but many different pieces of fabrics. On the one hand, this is due to the complexity of the shape of the human body with its curves and bulges, which need to be covered by a fitted garment. On the other hand, this is related to changing tendencies and trends, which constantly ask for new silhouettes. Hence, as a garment is composed out of multiple single surfaces and they have to be somehow connected subsequently, in order to form a complete garment. The mechanical behaviour of a single textile and the behaviour of a tailored garment out of the same fabric are different as the characteristics of the junctions of the single surface pieces influence the general comportment as well. For the combination of two fabric pieces there are several different methods:

The traditional way of combining two fabric pieces is by applying sewing techniques, where two or more surfaces are linked together with threads. Hereby, distinction can be made between different types of seams, such as the plain seams, the welt seams, the welding seams, decorative seams, etc. Their mechanical characteristics vary according the number of fabric layers and number of stitches and topstitches. Modern high tech textiles, especially water proof garments are welded instead of sewed, as the stitches would impact their performance. Decorative seams are stitching in various patterns on top of the outer fabric. Whereas the decorative seams influence less the mechanical behaviour, the seams containing multiple fabric layers can change the fabric comportment significantly. Therefore, if we want to accurately imitate those garment parts, the mechanical behaviour of the seam needs to be tested first. In the simulation system the seam behaviour is controlled with the seam stiffness parameter.

3.3.2 Multi-Layered fabrics

In order to give to a garment more stability in some areas for functional or aesthetical reasons, a second fabric layers can be added. This second fabric layer is either permanently fixed to the outer fabric (fusing) or it is a loose additional textile (interlining). Regarding the permanently fixed fabric layer the mechanical characteristics of the bonded combination of the two materials have to be measured for their accurate virtual re-creation. However this can be easily accomplished by measuring not the single but the fused fabrics.
For the non-fixed fabric layers this is however a more difficult task. On the one hand the combination of both characteristics is needed, but on the other hand, the fabrics are single layers and for an accurate prototyping they should be treated separately. Simulating two layers of textile is very challenging. First, a stable and robust collision detection and response algorithm should be used in order to accurately model the interaction between the two layers. This is very difficult to do because most collision handling requires a minimal distance – greater than the distance between 2 layers of fabric – to remain between the colliding objects. Second, a high number of polygons should be used, which would considerably slow down the simulation. Because of these two aspects it is suggested to also simulate the non-fixed fabric layers with only one virtual surface. Using mechanical characteristics which are a combination of materials, even the simulation of an endless amount of fabric-layers is possible with today's simulation systems from a technical point of view.

4. Case Study

4.1 High Fashion in Equations

Tailored out of exquisite materials and artful designed patterns, high fashion garments constitute the most sophisticated kind of clothes. The unique manufactured pieces, only affordable for a small circle of clientele, are not only envelopes for the human body, but artworks, visualizing cultural aspects, tendencies and trends. Historical haute couture garments are characterized by an additional aspect: Time specific garment details, which allow their affiliation to certain époques, become visible.
The computation of this kind of art pieces can thus be seen as the most challenging part in the field of virtual garment simulations, an area that was not touched on before. It represents new challenges for the computation system as well as for the realization of the design. With the 3D animation "High Fashion in Equations" MIRALab-University of Geneva brought to life virtually 18 Haute Couture garments from the 1950´s to the 1960´s after designs from Marc Bohan, Serge Guérin and Hubert de Givenchy, former assistants of the Swiss couturier Robert Piguet.

4.2 Design and implementation

The overall visual appearance of a garment (real or virtual) is influenced by two main components: The shape of the 3D garment, determined by the corresponding 2D pattern and the fabric material used which behaviour is influenced by its mechanical and physical properties.

4.2.1 2D Pattern

The creation of high fashion 2D patterns is a precise handiwork. Having the desired 3D shape in mind, a flat pattern is drawn by skilled experts according to pattern construction rules. Therefore, ancient garments of that period have been studied for a better comprehension of former pattern making methods [11]. The look of the garment silhouettes of the 1950's and 1960's is also influenced by the beauty ideal of that time. The post war period is characterized by the typical wasp waist.

The virtual garments have been composed with Miralab's virtual garment creation software, which imitates the real world tailoring process: the patterns are initially designed and cut in 2D space, placed around a virtual mannequin in 3D space, sewn together to make a completed clothing. New innovative design tools allow the fast alteration of the elaborated 2D patterns both in 2D and 3D with real-time preview of the 3D garment. During fitting, the system automatically evaluates the comfort of the garment on the overstated body with its wasp waist silhouette. Based on the mechanical interactions between the cloth and the body, the designer receives the feedback for optimizing the pattern shape. Other important features, inevitable for those challenging calculations, are a powerful collision response method able to simulate multilayer cloth with stability and robustness, complemented with an intersection recovery system for addressing the possible remaining problematic situations [12].

5.2.2 Fabric material

Since only precisely computed fabric characteristics can visualize the exquisite fabric qualities of high fashion garments, their correct derivation from real fabric characteristics plays an important role. Information on the fabrics used for those designs was limited to material descriptions regarding structure and fibre compositions. Therefore, similar fabric materials have been chosen and measured with fabric characterization experiments, to obtain strain-stress curves for the main mechanical and physical fabric properties, which were fitted with polynomial splines.

Figure 9 Example High Fashion in Equations

Finally, the garments are simulated using the accurately derived physical and mechanical fabric properties. During the animation, the garment follows the movement of the virtual mannequin. The movements of the mannequins have been inspired by poses of ancient drawings of that period.

5. Conclusion

Interactive design can already be used for creating fashion models that have enough realism for reproducing accurately the behaviour of real garments. Thanks to inputs measured from real fabrics along with good time-accurate numerical techniques, our system is able to compute realistic animations of complex garments.
The core technologies of this system are now being adapted to actual needs of the garment industry through collaborative projects, which deal on mechanical characterization of fabrics, virtual prototyping, manufacturing processes, e-commerce. Although some advances are still welcome in the area of efficiency and accuracy of mechanical simulation techniques, the challenge is now to create new tools that will ensure to the garment industry a smooth transition from tradition to novel possibilities offered by virtual simulation.

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