Simulation and Visualisation of Virtual Textiles for Virtual Try-On

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Simulation and Visualisation of Virtual Textiles for *Virtual Try-On*

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ABSTRACT

The correct simulation and visualisation of textiles comprises many research fields such as mathematics, physics, materials science, and computer graphics. It consists of modelling the physical behaviour of textiles based on real data of garment patterns which have to be placed around an avatar. Therefore efficient numerical algorithms have to be developed to solve the appearing differential equations. Finally the obtained results are displayed photorealistically). The aim of the national research project "Virtual Try-On" consists in providing a prototype of a virtual try-on scenario in a real shop or the internet realizing cost-efficient made-to-measure wear. In this article we present the whole process chain from the choice of clothes up to the final visualisation and the individual evaluation of fit.

Keywords: Virtual Try-On, Prepositioning, Simulation, Visualisation

1. Introduction

The process chain for virtual try-on and final visualisation consists of several steps. First, the automatic prepositioning, providing a good initial simulation state for the cloth-patterns with according seam information. Second, the physical simulation calculating the drape of the garment, where measured material data are integrated. Finally the realistic and interactive visualisation using measured reflection properties and natural illuminations provides the *Look & Feel* of the materials as shown in Figure 1. Figure 2 shows the different steps within the process chain.

Fig. 1. An example of physically simulated clothes rendered with measured reflection properties and realistic illumination conditions.

There exists a huge amount of literature and solutions for each component of the virtual clothing scenario. For the interested reader we refer to the cited articles and the references therein. Further references and a good overview can be found in the text books by P. Volino and N. Magnenat-Thalmann (Volino and Magnenat-Thalmann, 2000) and D. Breen and D. House (House and Breen, 2000). The present article aims at giving an overview of the different fields of research within the virtual try-on section describing them at the example of the national research project Virtual Try-On.

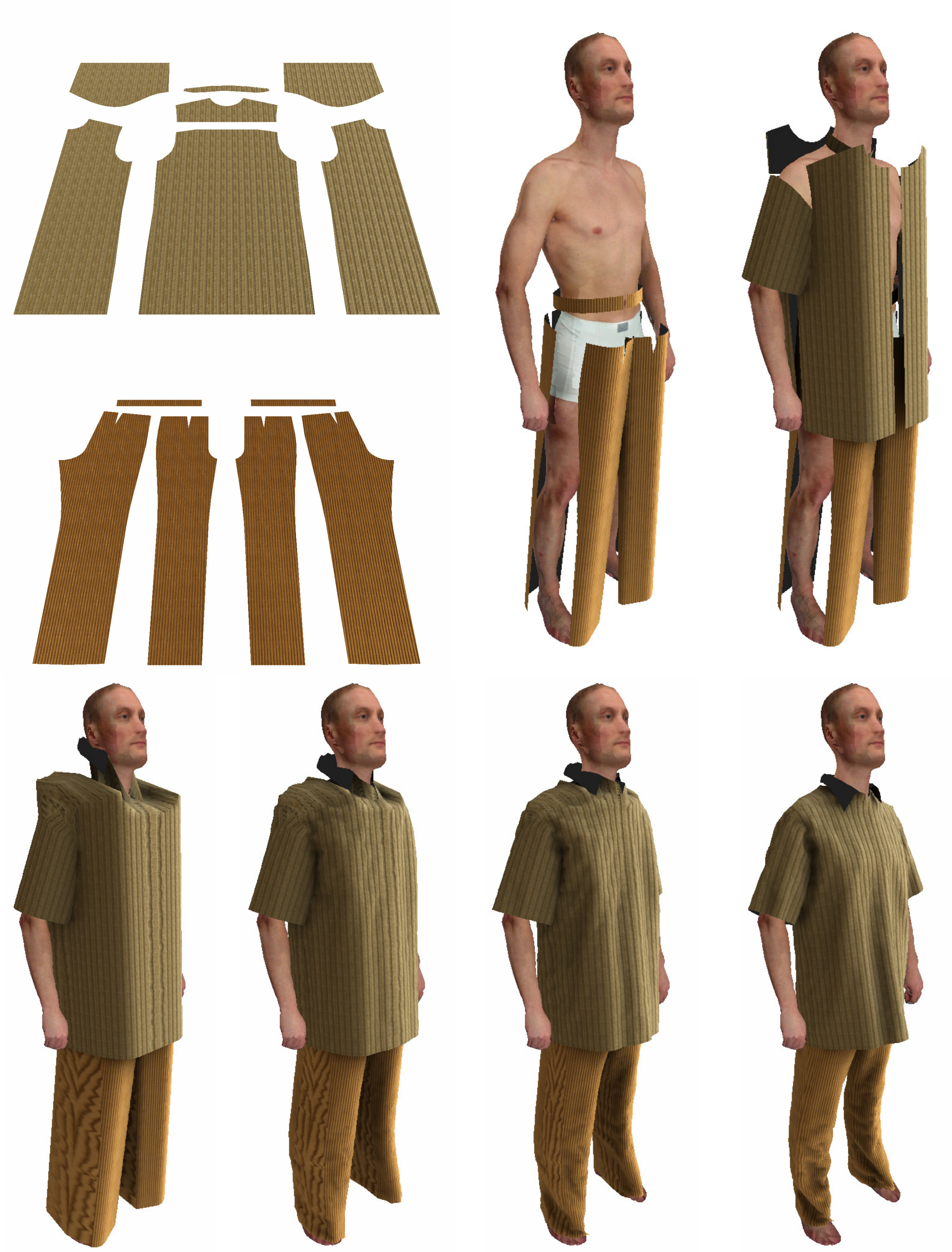

Fig. 2. Virtual Try-On process chain. Cloth patterns of a garment (first row on the left) are prepositioned around an avatar (first row on the right), sewn together, and the drape of the final cloth is calculated and rendered (second row).

2. Prepositioning

The first element of a production chain in the garment industry is a highly-specialized CAD-system [1, 21]. There, all cloth patterns are built and described as two-dimensional boundary curves enriched with all the additional information that is needed to physically construct the final garment. For example, there is the *sewing information* that describes how the cloth patterns must be sewn together. Of course this information is also required, if we want to dress a virtual human with virtual garments. In a virtual try-on context, one approach is to build the virtual cloth patterns with the geometry information from the CAD-systems, to sew them together virtually with the appropriate sewing information and to simulate the real try-on process. But a simulation of the real try-on process can be very complex, e.g. if you think of a person that tries to get in a small sweater. However, there is a much easier way to implement a virtual try-on, which is proposed in (Volino and Magnenat-Thalmann, 1997 & 2000). There, the single cloth patterns are positioned manually, e.g. by a computer mouse, around a virtual human body. After this *pre-positioning* step the sewing process is simulated directly on the human body by physically-based simulation methods. This approach can be applied in e.g. the film industry (Visual Effects Society, 2001) or - more generally - when creating animations.

Time-critical applications require automated and faster mechanisms. There is e.g. the *virtual boutique*, where a customer wants to examine the fitting behaviour of a chosen garment on his own virtual twin. In this context a pre-positioning by user interaction should be replaced by an automatic pre-positioning. Therefore a new approach was proposed in (Fuhrmann, et al., 2003; Gross, et al., 2003), where the virtual cloth patterns, which consist of triangle meshes, are positioned automatically on bounding surfaces, that enclose the body segments, e.g. torso, arms, and legs. The resulting pattern positions serve as initial positions in the subsequent physically-based sewing process, so that you have to take care of several aspects. First, there is the problem of high tension in initial positions of physically-based simulations, which may result into numerical instabilities. But that problem is solved by using developable bounding surfaces, like cylinders or cones. They ensure minimal stretching when mapping a two-dimensional triangle mesh onto them. Furthermore, you have to avoid collisions between the human body and the cloth patterns as well as between the cloth patterns themselves. In the last decade many techniques (Bridson, et al., 2002; Baraff, et al., 2003; Mezger, et al., 2003) have been proposed, which are able to resolve collisions in physically-based simulations, but nevertheless collision-free initial positions will result in a much faster computation time. Positioning cloth patterns seam beside seam guarantees that the distance between two corresponding sewing lines is as minimal as possible.

With that approach it is possible to pre-position many garments simultaneously. Therefore, a series of bounding surfaces lying one upon the other are computed, onto which the cloth patterns are positioned very compact around the human body and with no collisions in most cases. A dressing order can be defined very simply just by changing the sequence under which the garments are processed in the positioning step. That means, you easily can decide if you want to wear your shirt inside a pair of trousers or outside just by positioning the two garment patterns in the right order.

3. Cloth Simulation

The preposition of the patterns being a good initial state for the following module, the physically based cloth simulation is responsible for sewing the prepositioned garments along the seam lines and for computing the drape of the clothes on the avatar. Therefore the material properties are modelled consistently, the equations of motion for the drape of cloth have to be formulated which have to be discretised and solved efficiently. Hence, the dynamical behaviour of clothes can be visualised providing valuable information for the customer about the actual fit of the chosen virtual garment. In this section, we describe the cloth simulation engine TüTex which satisfies the requirements for fast and realistic animations of clothes. First, we describe the material modelling, the physical model, and the numerical algorithms. Then, the necessary collision detection and response techniques are illustrated. Finally, we present a first prototype for interactive manipulation of the clothes during the simulation.

To compute realistic animations of clothes, we developed an efficient model based on finite elements for visco-elastic, highly flexible surfaces. Kawabata measurements (Sawabata, 1980) hereby provide the material parameters for the simulation. Textiles show very different physical behaviour in weft and warp directions, so we model elastic and viscous material parameters for the two directions independently. Material measurements are carried out for the two Young moduli, the shear modulus, and the Poisson number, which controls the transverse contraction. Additionally, the bending moduli describe the curvature elasticity in the weft and warp directions. Hence the material behavior becomes apparent in different simulation results (Figure 3).

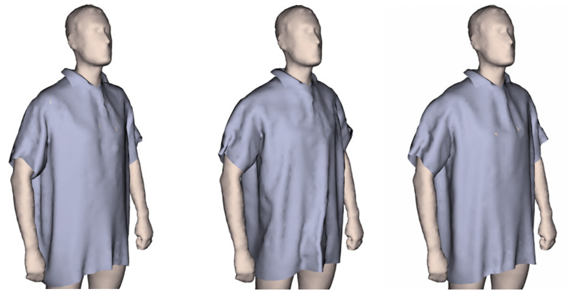

Fig. 3. Various materials for a shirt: (a) wool/viscose, (b) wool, (c) polyester/ polyacrylics/acetate.

Dynamic Kawabata experiments also provide visco-elastic data such that we can model the exact hysteresis effects of the corresponding moving tissue.

The underlying equations of motion are based on the continuous elasticity equations. They are semi-discretised in space by an adapted finite element method with subsequent time integration. Since textiles are very flexible, i.e. have a low resistance to bending, a linear formulation of the deformation tensor cannot be used which is only valid for small deformations. In our approach we construct a co-rotated reference frame for every finite element where we can calculate the inner forces of the tissue (Etzmuβ, et al., 2003). Finally the time integration is particularly designed for numerically stiff equations which result for textiles. We use an implicit Euler method where we apply an inexact Newton method and solve the resulting sparse linear equation system by a conjugate gradient method. For high resolution methods we propose a parallelisation for the implicit time integration (Keckeisen and Blochinger, 2004). With this model, we are able to assemble garments from CAD cloth patterns, seam these together, and animate the cloth in dynamic scenes with any chosen material properties (see figures 2, 3, and 6). This results in a physically accurate but also fast simulation. External forces like air resistance and wind effects are integrated as well (Keckeisen, et al., 2004) and considerable enhance the visual appearance of the draping. Moreover, by solving the movement equations for the draping, we can calculate the clothing on a moving character driven by animation or motion capture. Here, the visco-elastic effect becomes apparent, the user can realistically judge the behaviour of the cloth and hence obtains a better impression of its fit. Moreover, real-virtual comparison shows good correspondence of real and simulated garments (see Figure 4).

Fig. 4. Comparison of a real and a simulated woman's dress.

Interaction of the textile with itself and other objects plays an important and crucial role in physically based animation in order to model collision and friction and to produce realistic behaviour. Hence, it must be modelled and integrated carefully into the equations of motion described above. To reduce the quadratic complexity of collision detection, we use hierarchies of discrete oriented polytopes (k-DOPs (Mezger, et al., 2003) to approximate the objects of the simulation. As the meshes in cloth simulations deform almost arbitrarily, efficient build and update mechanisms for the hierarchies are essential. An overview over these different update mechanisms and over other collision detection methods for deformable objects can be found in (Teschner, et al., 2004). In our implementation the hierarchies are built by a top-down splitting method and can be traversed very quickly while they can be efficiently updated by merging the bounding volumes from bottom to top. Figure 5 shows such an 18-DOP-hierarchy for an avatar. Since self-collision is crucial for realistic cloth simulation, it can not be neglected by the collision detection and response. We combine the idea of normal cones with the k-DOP hierarchy to estimate the surface curvature for the region covered by a hierarchy node. Thus, parts of the textiles, where self-intersections are impossible due to their low curvature, are identified and skipped during the self-collision test. Moreover we use time coherence to skip parts of the actualisation process.

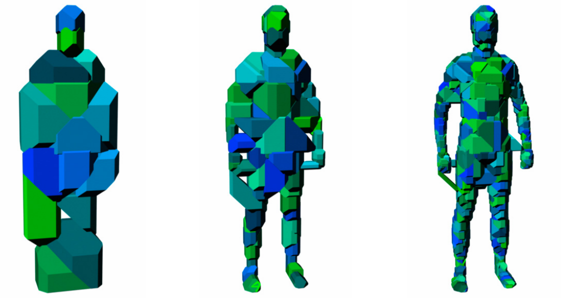

Fig. 5. Different levels of a k-DOP hierarchy.

For the collision detection process the hierarchy is traversed and the nodes are tested for collision. If two tested nodes do not collide the collision detection can be stopped. Otherwise we calculate the distance of the leaves applying edge-edge and vertex-triangle tests.

After all collisions have been detected, they are resolved using a collision response scheme. In the presented system therefore two different collision response methods (Kimmerle, et al., 2003) are combined: *Constraint based* collision response and *force based* collision response. For most collision cases the constraint based method is used, because it turned out to be exceedingly valuable in order to avoid collisions before they occur and to achieve large time steps. The constraints are directly integrated into the equation solver and yield very smooth animations. Additionally, vertices that are already penetrating the other object can be reset to the surface. For self-intersection we define repulsive force fields to prevent parts of cloth to intersect or to separate them in case they have already collided.

Fig. 6. The process chain for virtual try-on. Several steps of the simulation process.

For the photorealistic rendering we then provide the three-dimensional meshes of the deformed garment with texture coordinates. For time critical applications like the internet a Java based simulator has been developed (Fuhrmann, et al., 2003).

Here only the important material parameters are taken into account and collision detection is done with the help of distance fields (Fuhrmann, et al., 2003). They are very efficient for static meshes and in addition provide more information of the outwards direction for the collision response.

When we try-on real clothes, we frequently adjust the garments on our body manually (see Figure 7).

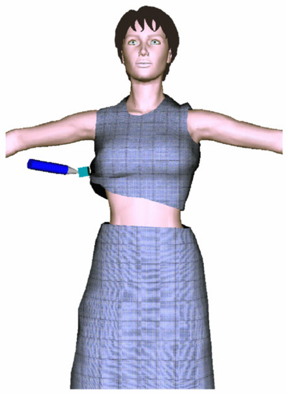

Fig. 7. Interactive adjustment of cloth.

To provide an equivalent in a virtual try-on scenario, we developed interaction techniques which allow to select and drag parts of the garments during the physically based simulation (Keckeisen, et al., 2003; Wacker, et al., 2003). In our system, this can be accomplished by utilizing Virtual Reality input devices that allow 6 degrees of freedom to drape the simulated garments into shape, just like a real person does after putting on real clothes. Moreover, it is a basic tool for virtual garment design. In our environment, garment patterns can be created, sewn together, and virtually tried on an avatar.

4. Photo-realistic Visualisation of Clothes

The high-quality photo-realistic visualisation and the three-dimensional rendering of the cloth and the virtual customer is the end part of the process chain. Special care is taken of the simulation of the physical correct reflection properties of the material surfaces. The customer should get the

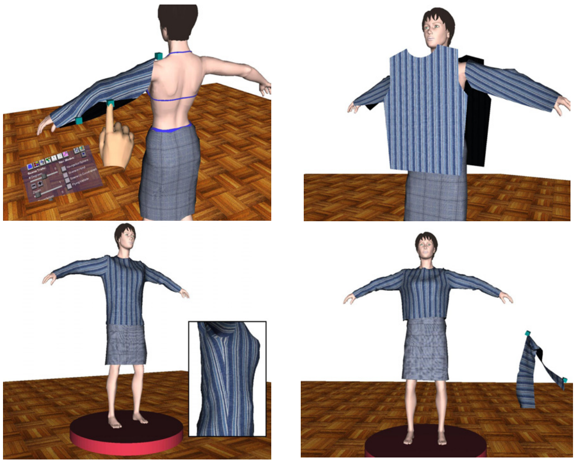

Fig. 8. Virtual Dressmaker: Some stages of a virtual design process.

Look & Feel of the material just by looking at the rendering. Furthermore, it is important to incorporate real-world illumination conditions, e.g. the conditions at the point-of-sale (POS) or under bright sunlight.

A complete measurement laboratory was set up to allow the automatic measurement of the reflection properties of flat material samples (Figure 9).

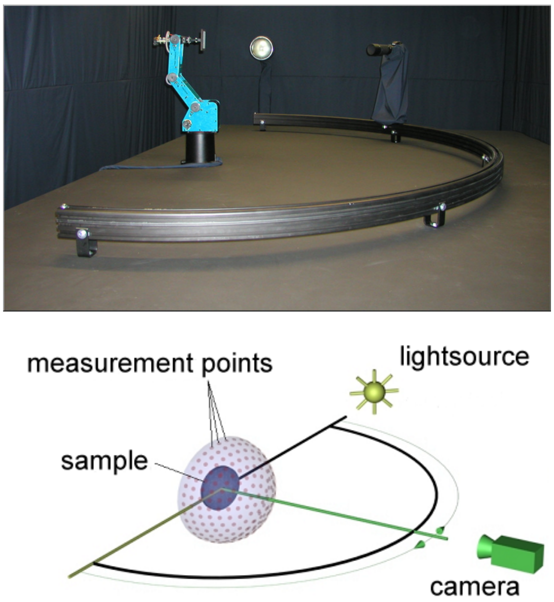

Fig. 9. Laboratory setup. The robot, shown in the center, is holding the sample. The light bulb is shown in the back. The rail system with the CCD camera mounted on a little wagon is attached to the table around the robot. The lower image shows a schematic view of the setup.

It consists of a robot, a rail system with a moveable 14 Megapixel high-end digital camera and a HMI (Hydrargyrum Medium Arc Length Iodide) light source, which simulates the sun emission spectrum. The whole lab works automatically and is controlled via computer programs. To capture all effects of the material, high-dynamic range images are made. With this effort, a complete bidirectional texture function (BTF), as introduced by Dana et al. (Dana, et al., 1999) is automatically obtained. A BTF completely describes the appearance of a flat material sample viewed and lit from different directions, hence captures important mesostructural effects like subsurface light transport, self-shadowing, inter-reflections, occlusions and foreshortening. Some of these effects can be seen in figure 10. The measurement of these effects is essential for a photo-realistic reproduction. The visible part of the undulating mesostructure of the corduroy sample and the resulting brightness for example are subject to high variance.

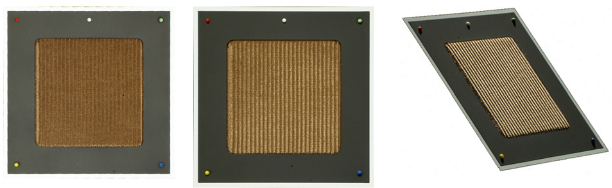

Fig. 10. Different views with different illuminations of the corduroy sample. Left: frontal view, frontal illumination; Center: frontal view; sideways illumination; Right: inclinated view.

Figure 11 shows a comparison between a geometry textured with BTF data and the normal frontal viewed texture under the same illumination. The close-up views illustrate the qualitative differences and the BTF effects. The VTO textiles are measured out of 81 different viewing directions. For every viewing direction 81 different lighting directions are used, resulting in a data set of 6561 images per sample.

Some of the measured materials are made publicly available on an internet site [3]. Further details of the measurement process can be found in Sattler et al. (2003).

The effective usable resolution due to the perspective and the sample holder parts in the image is 800x800 pixels, and the captured images represent a data amount of 90GB. This amount is reduced by registering only a representative part of

Fig. 11. Effects of using BTF data of different materials under natural illumination conditions. The images on the left side show the BTF rendering, while the images on the right side were rendered using only normal texturing (frontal texture only). The mesostructure and the characteristic reflection properties are completely missing, the Look & Feel is gone. This can be seen especially in the close-ups. As high-dynamic range backgrounds some data from (Debevec, 1998) is used.

the surface. This part is cut out of the corresponding images. To allow the texturing of large objects, the images are made repeatable using blending methods. This reduces the data amount to roughly 1.2 Gigabyte per material. For further reduction of the data, a principal component analysis (PCA) as well as clustered PCA (Müller, et al., 2004; Sattler, et al., 2003; Hauth, et al., 2002) are applied resulting in up to 24MB for a 256x256 Pixel BTF. The chosen texture size depends on the material structure and quality requirements. These methods allow fast decompression, advanced multi-texturing algorithms and are therefore especially suitable for rendering with todays graphics hardware, even on consumer PCs.

The comparison between "real" and "virtual" cloth shows, that using only point or directional light sources results in a non natural illumination condition. Therefore, we integrated the possibility to use high dynamic range images (HDRI) to allow for a real-world illumination. To acquire the HDRIs from real world locations, e.g. shops, a portable measurement system was build. A chrome sphere is photographed with increasing shutter times and recalculated into an unfolded cube as shown in figure 12.

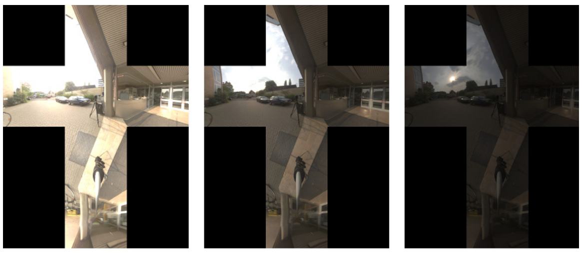

Fig. 12. Images with different shutter times, showing the illumination conditions at the entrance of the University of Bonn.

The surrounding environment is reflected on the sphere and can be used to generate a cubic high-dynamic environment map as shown in figure 13. The data stored in this map reproduces the high dynamic differences of several parts in the scene (bright sun, doors in shadows) and is used to illuminate the geometry. The interactive change of viewing positions and HDRIs was integrated into the BTF renderer to allow the customer a high degree of freedom for her/his judgment of the cloth.

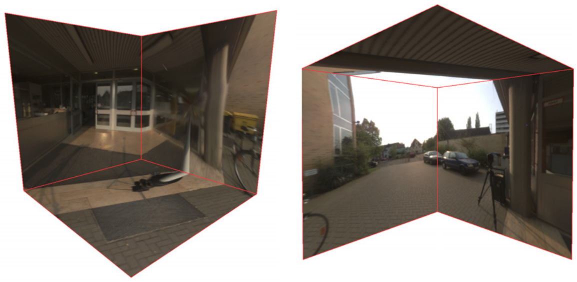

Fig. 13. Two views of a cubical environment map for reproduction of the illumination condition.

Another important part is macroscopic self-shadowing. It is an important visual clue to recognize the draping of cloth and to visualise folds. Therefore, we compute a local shadow value for each point of the geometry as shown in Ganster et al. (Banster, et al., 2002; Sattler, et al., 2003). This is done using a hemi-cube approximation of the hemisphere over each surface point. Roughly speaking, we evaluate which part of the environment is seen from each point of the surface and which part is occluded by other geometry. If, for example, half of a white environment is blocked by the geometry, the shadow value will be 0.5. The incoming radiance out of discretised directions is determined and stored. Interpolating between values of neighbouring vertices yields in a smooth result. This method also calculates the correct shadowing from other objects onto the main geometry. Using high-end graphics accelerators and shading language programming reconstructing the BTF out of the principal components of the PCA and incorporating the computed shadow information, it is possible to render at interactive frame rates (Sattler, et al., 2003; Müller, et al., 2004). Comparisons with other rendering methods shows the superior quality of PCA and LPCA based BTF rendering (Meseth, et al., 2003; Klein, et al., 2003). With this method and the help of specific display devices, e.g. a *Virtual Mirror*, it is possible to show the customer the virtual cloth in life size and it is possible to judge the fit and look on the customer's body at the point-of-sale. If the customer is moving in front of the mirror, the cloth geometry changes. Therefore, geometry simulation and lighting computations have to be carried out in real-time. Due to the computational complexity of the draping simulation as well as the lighting simulation an algorithm was developed, that is capable to estimate the cloth geometry together with shadowing information. It is based on a statistical evaluation of geometry and shadow information which is pre-computed for most postures and typical movements of humans trying on a certain cloth. Another algorithm was created to extend existing animation sequences for presentations in a non-trivial way (Sattler, et al., 2004). The project definitely demonstrates the great improvement of the visualisation of cloth by using measured reflectance properties of real world materials. In addition, the greatly improved realism of real reflectance properties of cloth under natural illumination conditions provides the user with a much better *Look & Feel* of the material than previous rendering techniques. This way, the client can already judge physical material properties based on the visualisation. During the project it became clear, that the collection of reflectance properties of the different cloth materials used in the textile industry is a critical part in the whole visualisation chain. In the context of the mass market more optimized labs will be necessary to acquire all this data. A first sketch of such a setup can be seen in figure 14. Using more than 150 digital consumer cameras and no moving parts the acquisition time can be reduced to less than half an hour per material. Last not least it should be mentioned, that based on the outstanding visualisation results achieved in this project also further applications of this technology in the area of the automotive industry and architecture were initiated (Meseth, et al., 2003 & 2004).

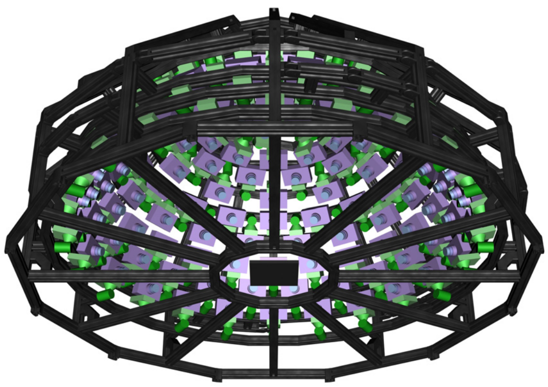

Fig. 14. New laboratory setup concept sketch. Using more than 150 digital consumer cameras and no moving parts the acquisition time can be reduced to less than half an hour per material.

5. Summary

Based one real input data ranging from CAD patterns and measured material data to real reflection properties we obtain a realistic impression of textiles. Therefore a customer can decide on the fit of the chosen virtual cloth. For the whole process chain high quality modules are developed to achieve this goal. A prepositioning step determines the best initial position for the subsequent simulation. In the simulation step we provide a realistic calculation of the drape of the chosen clothes by integrating measured material data to reflect the real properties of the tissue. In the final visualisation we enhance the simulation by measured BTF data which provide a natural Look & Feel of the shown garment.

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