Automated Generation of Human Models from Scan Data in Anatomically Correct Postures for Rapid Development of Close-Fitting, Functional Garments

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Abstract

During the last decade, 3d scanning of human bodies got widely-used in apparel industry, but mostly just the measurements are taken and the pattern construction process is done still in 2D. Effective processes to bring a body scan anatomically correct into body postures and movements that are typical for garment usage, e.g. high-performance sports, are missing. Our approach uses a template model with an optimized mesh structure, a kinematic system composed of skin, muscles and skeleton parts, and anthropometric landmarks. The landmarks are used to scale each bone of the template model to the size of the scan and to adjust the posture exactly by rotating the bones. The muscle system and the skin follow the changes of the bones. This skin can now be used to generate automatically a mesh with the exact surface of the body scan and identical connectivity, which enables us to transfer the kinematic system and behavior easily and automated. We demonstrate results for a lower body part of a human being. All modeling and animation work was done in *3ds max* [6].

Keywords: 3d body scanning, automation, character animation, human body simulation, musculo-skeletal simulation, template

1. Introduction

A perfect suit needs more than the static data of a body scanner. When the body moves, some parts of the body are bulged and others are stretched. If a person bends forward its dorsal length increases by up to 9 cm [15]. This is measured by the principle of Schober and Ott: Four markers are positioned on the spine in upright posture, two on the thoracic spine with a distance of 30 cm and two on the lumbar spine with a distance of 10 cm. At bending forward the distance between the markers increases up to 9 cm and can be measured. This effect can be observed in many types of sports, e.g. skiing, bicycle racing, speed skating. In high-performance sports an exact fit is highly important to achieve the desired athletic performance. Therefore it is necessary to move the static scan data anatomically correct into the typical postures of the athlete.

Although body scanners and commercial software solutions for flattening 3d patterns into 2D are widely-used in the clothing industry, the data of body scanners is mostly used for determining measurement lengths only. These values are the input for the traditional pattern construction technology in 2D without consideration of any body shape deformations at movement. Animation of each scanned person is too elaborate and expensive, a fast and reliable process to bring scan data in typical postures is missing.

In this paper we describe an automatic technique for fitting a template mesh to a scanned body surface and transferring its kinematic system (skin, skeleton, muscles), postures and movements to it. All time-consuming work is put into the template model and prepared in a way that allows transferring the kinematic system. To make the movements of the template model anatomically reliable, it is important to add muscles to the skeleton. Especially the postural muscles (flat muscles, often not visible as muscle work) are important for keeping the skin at a minimum distance from the bone when bended, e.g. in the groin, in the arm bend, on the backside of the knee. The skeleton muscles are responsible for movement and have often an obvious influence on the skin, like biceps in the upper arm or lower leg. Both groups of muscles have to be modeled and must be connected anatomically correct to the skeleton.
Our target is a fast reliable process for generating animated human body model with reliable measurements in every posture.

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2. Related Work

The main modeling methods of human models are creative, interpolative and reconstructive. Reconstructive models can be obtained from different input channels, e.g. stereo data, structured light, 3d scanner, algorithms to combine 2D images. All these methods generate visually convincing solutions without immediate access to the underlying structures like skeleton, muscles, and body deformations. Interpolative methods use a set of sample models to create new models by interpolation. One of the most popular methods can be found in the work of ALLEN [2]. ALLAN uses range scans to build up a database of 250 surfaces with the same overall structure, which allows morphing between the individual shapes of bodies. This process relies on a set of anthropometric landmarks provided in the CAESAR (Civilian American and European Surface Anthropometry Resource) database of ROBINETTE [13]. MAGNENAT-THALMANN et al.[10], [11] uses recorded mass and form data to create a new model from a template using the measurements of scan data. JU et al.[9] uses a template approach to defining cage-based skinning which is reusable.

The main approaches for modeling body deformations are anatomic modeling and example-based modeling. Anatomical modeling always uses a skeleton, but not necessarily a model representing the muscles. One or more bones influence each vertex of the skin, the value representation of the bone influence is called skin weight, and the process is called skinning. AU [4] shows an approach for generating automatic skeletons by mesh contraction. SCHEEPERS et al.[14], WILHELMS and VAN GELDER [18] describe the anatomic and mathematical basics of the relation between bones, muscles and skin. [18] describes how the shapes of muscles have to be recalculated when the joint between the start and end point of a muscle moves. Setting frames and interpolating between them is used to animate muscles. AUBEL [5] introduces an interactive muscle builder to add muscles to a skeleton interactively. SUEDA [17] shows a musculotendon simulation model for hand animation that is reusable and can be plugged into the usual animation process to add muscle work to a bone-driven animation.

ALLEN [1] presented an example-based method for calculating skeleton-driven body deformations. He uses range scans of body parts to extract body deformations and interpolate between them. For every pose a range scan is necessary which makes this process quite elaborate. This process cannot be applied to complete postures, which cannot be scanned because of occlusions and grazing angle views. Poses are reconstructed of independently posed partly scans. 96 scans and nearly 150 markers are necessary to capture the upper body (arm, shoulder, torso), which is a quite big effort. ANGUELOV [3] acquires the SCAPE method (Shape Completion and Animation for PEople), a data driven method for building human shape models. The system is learning the space of pose deformations by a set of scans of a single person in different poses and can learn the space of body shapes from different poses of different people.

In general, we follow the template-based approach acquired by ALLEN [2] for body scans and keeping identical connectivity for all meshes that allows vertex-to-vertex transfers.

Our contributions are:

- System of landmarks enabling us to automate processes
- Fully scalability of the bones system regarding bones lengths
- Anatomic based realistic muscle system
- Linkage of the muscle system to the skeleton and fully scalability of the muscle system regarding bones lengths
- Generation of scaled template for specific scan data, no database of templates is necessary
- Fitting algorithm to match the scan surface exactly
- Transfer of kinematic system, postures and movements to the scan data

3. Acquiring and Processing Data Meshes

We acquired our surface data representations of real human beings using a *Human-Solutions* [16] whole-body scanner, which captures range scans from four directions simultaneously. The surface consists of about 130’000 vertices. If there are holes in the mesh they have to be closed manually or by using hole-filling algorithms as described by ALLEN [1]. The posture is a classical scan posture. The mesh is not structured in a special way and too dense for animation. Figure 1 shows on the left side a sample mesh surface and a detailed view of a leg.

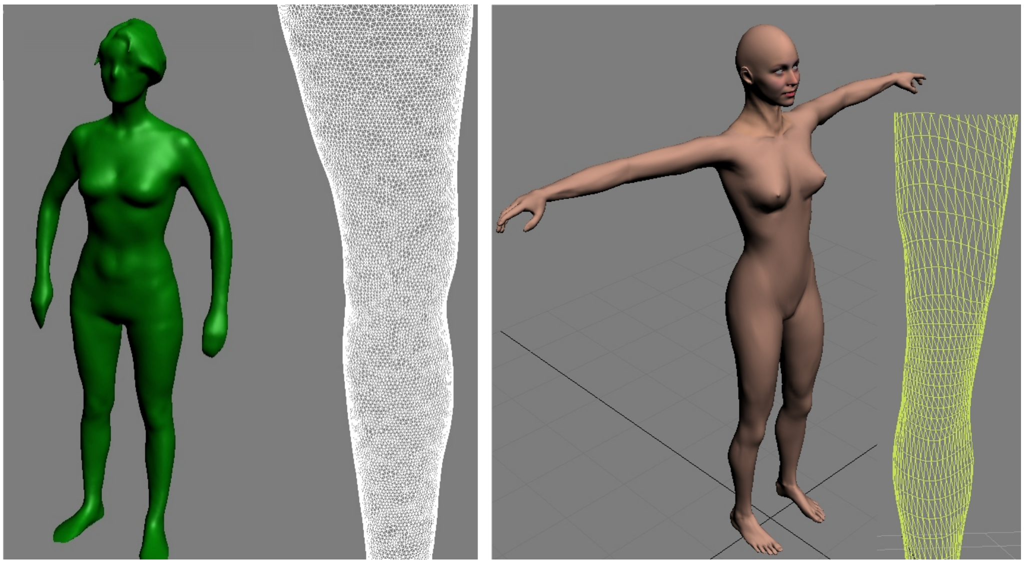

Figure 1: Surface Data and Mesh Structure of Scan Data (left) and Template Model (right)

Our template model uses the skin mesh delivered by the plug-in *ACT1.6* [7] for *3ds max*. We used only the mesh for our work; the delivered skeleton and muscle models were used for verification only. The plug-in does not support current versions of *3ds max* and cannot be used. Figure 1 shows on the right side the template mesh surface and a detailed view of its leg.

4. Processing Template Model

The template model is the basis for all generated models out of scans data. All modeling, skinning, animating and optimizing issues have to be done for it. These processes are time-consuming, but have to be done only once. All attributes and properties have to be transferable to a mesh using identical connectivity.

4.1 Mesh Structure

The density of the template mesh model did not meet our precision requirements everywhere. At the knees and the elbows we have hinge joints, i.e. one movement axis and two main movements (moving the lower arm up and down). For bones connected in that way, the mesh density increases on the inner surface and decreases on the outer surface, when one bone is bulged towards the other one. In outstretched state, the inner part has the minimal density and the outer part the maximal density. If the mesh gets too fine in the bulges it is difficult to control it. So we had to increase the mesh density in all parts but the arm bulges, the backside of the knees and the armpits. The hands, the feet and the head are not considered in our method and have not been changed.

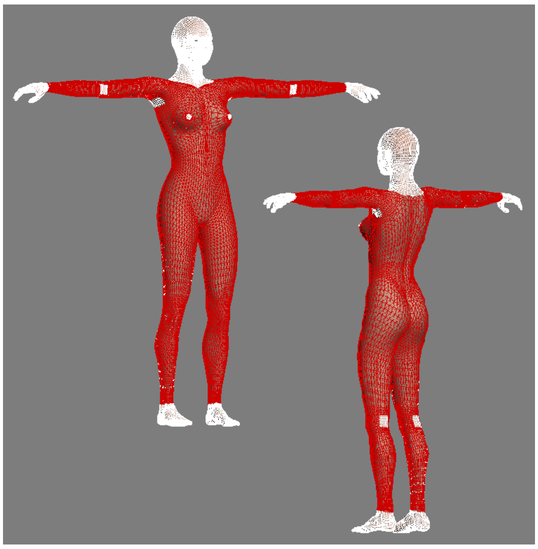

Figure 2: Regions where the mesh density has to be increased

4.2 Landmarks

For automation reasons we need some virtual markers matching anthropometric points of interest, i.e. links (elbow, knee, shoulder, wrist, etc.) and other positions (waist, hip, crotch, etc.). These points are called landmarks in the following. The landmarks should keep their relative position at scaling and movement of the template model. So, they have to be connected with the kinematic system. Figure 3 illustrates the defined landmarks.

To adopt the size and posture of a scan automatically, about 20 anthropometric landmarks are required. For the template model they are defined and connected to the skeleton, for each scan data they have to be set manually once. Although some scanner manufacturers offer software solutions for determining the landmarks, we decided against it to be independent of third parties.

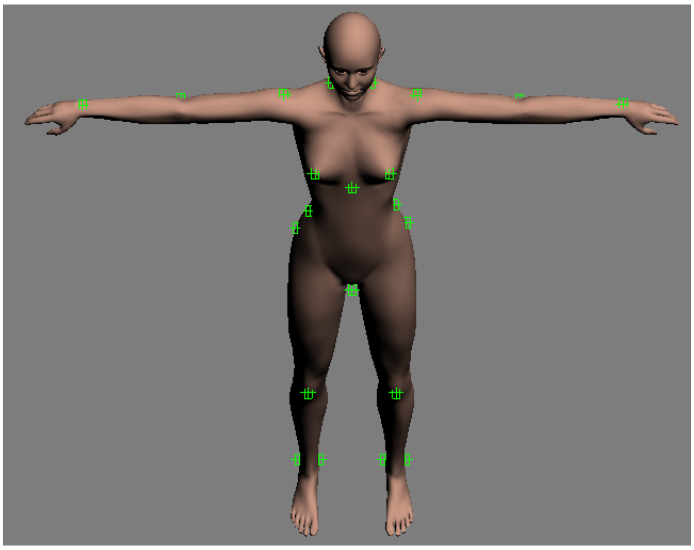

Figure 3: Landmarks of the Template Model

4.3 Kinematic System

The kinematic system consists of the skeleton, the muscle system and logical connections between

- bones and bones,
- bones and muscles,
- bones and landmarks.

Adjustments of skinning weights belong to the kinematic system as well.

4.3.1 Skeleton

The skeleton is a standard bone system of *3ds max* [6] called *CAT* (*Character Animation Toolkit*) with the predefined rig *Base Human* loaded. We adapted this bone system and added some extra bones. For defining the bone system of the template model, especially for defining the exact position of links, we used the skeleton of the *ACT* plug-in [7]. The patella is e.g. an extra bone with a big influence on the skin, but in a very small region. Therefore we need a separate bone representing it. If the knee is bent, the patella keeps visible and on top (see figure 4). The goal is a skeleton that is a good approximation of the real anatomic correlations, but not too complicated for animation and automation. For rigging we use an inverse kinematic system. All skin weights have to be set in a reasonable way. This follows the standard way of animation and is not described further.

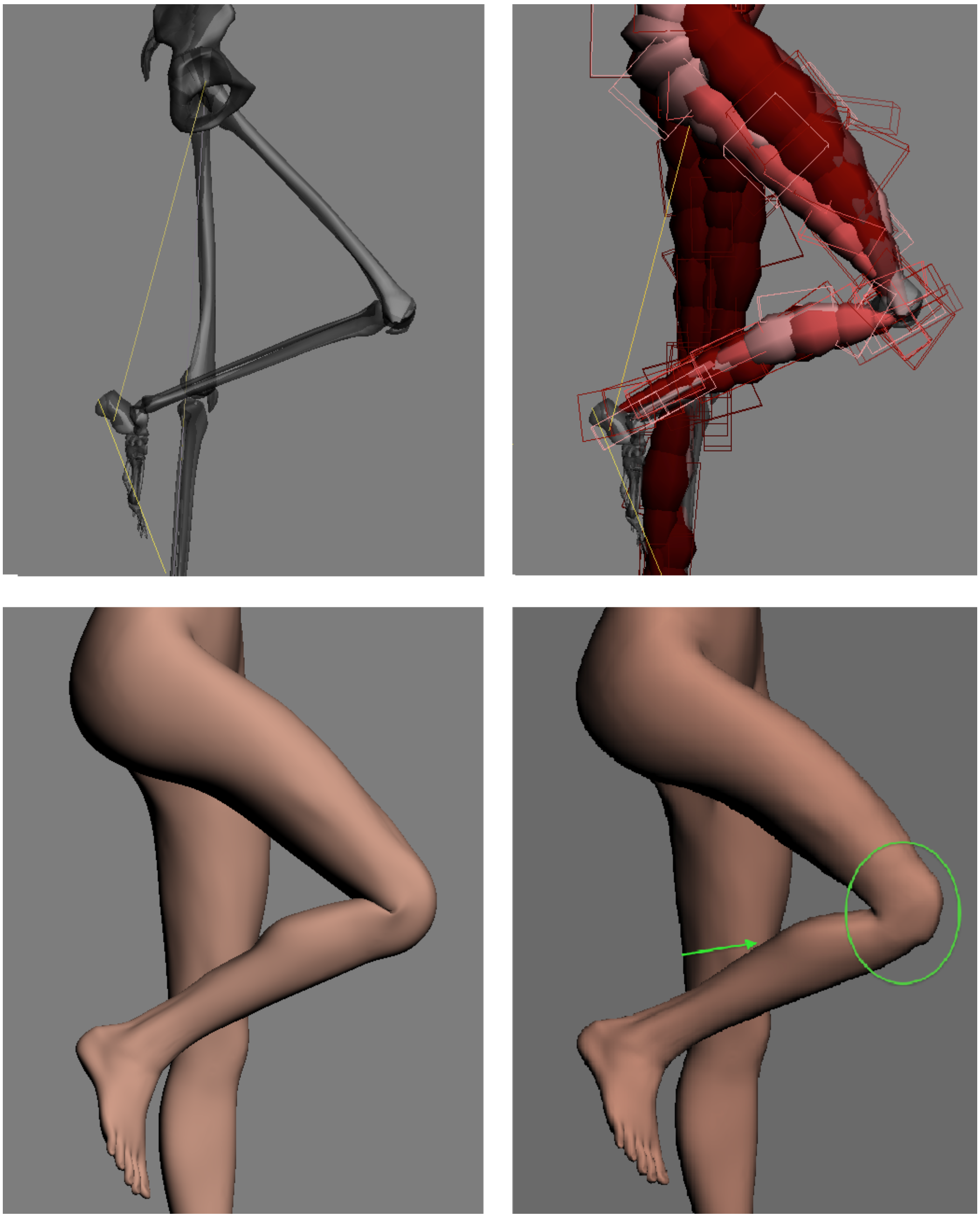

Figure 4: Knee region without (left) and with (right) muscle system

4.3.2 Muscle System

The muscle system consists of two kinds of muscles:

- postural muscles (flat, necessary for holding a posture)
- skeleton muscles (necessary for movement, e.g. biceps)

We model the postural muscles near under the surface of the skin; muscles near the bone and very underneath are insignificant. The postural muscles take care that the skin does not fall below a minimum profile. If we look at the knee region, the skin on the side of the knee folds like a hosepipe, if we use only bones (see figure 4, left bottom). With muscles underlying, the skin stays more continuous and looks more realistic (see figure 4, right bottom). Because we need realistic circumferences of all limbs in all postures, we model a lot of postural muscles to avoid pulling the skin too tight towards the bones at bending.

The number of skeleton muscles we model is small in comparison to the postural muscles. The principle is shown for the biceps in the lower leg. When it is bend, the muscle contracts, shortens and

gets thicker. This effect is visible from outside the skin, figure 4 (right side) illustrates it for the muscle itself and the skin.
The bases for modeling all muscles are the illustrations in the anatomy book [14] and the muscles of the plug-in ACT [7]. All skin weights have to be controlled and set in a reasonable way.

The muscles have start and end points and some control points for e.g. curvature and angles of tangents. These points have to be linked to the corresponding bones carefully to make sure the muscles act in the correct way when the bones move or rotate. These points have to be updated when the related bones are scaled. This enables us to move the muscles with the skeleton and to scale the complete bone-muscle-system.

The scaling process is done in two steps: First the complete template model is scaled to the body height of the scan; second each bone is scaled to the length of the corresponding part of the scan. The posture is adopted by rotating the bones from top to down, i.e. for the arm we will start at the shoulder, proceed with the elbow and end with the wrist to match every landmark. The kinematic system of the template model allows the muscle system and the skin to follow the changes of the bones.

4.4 Postures and Movement

With a complete kinematic system and reasonable skin weights the template mode can strike different poses now. We choose some poses with extreme link angles for verifying the kinematic system and the skin weights. If necessary, we make adjustments and control the impacts of the changes in the other poses.
Movements are implemented by using key framing technology, which interpolates between different poses. Alternatively, movement can be taken from motion capturing data. The movements can be defined in different layers and be combined freely. Each movement layer can be saved and loaded.
When we are satisfied with all body deformations at all postures and all movements, the template model is finished and completely animated with a kinematic system following anatomic rules.

The template mode strikes the scan posture now. This is the entry point for all scan models to be processed.

5. Processing Scan Models

The process of transferring the mesh structure, the kinematic system, the skin weights, the poses and movements from the template model to various scan models is widely automated. Nevertheless each process step has to be taken carefully and the intermediate results have to be checked. Some manual adjustments may be necessary.

5.1 Resizing

First of all, the whole model has to be resized to the height of the scan model. It is a linear scale in all 3 axes with the scale factor

$$f_{scale} = \frac{h_S}{h_T}$$

where

$$h_S = body\ height\ of\ the\ scan\ model$$
$$h_T = body\ height\ of\ the\ template\ model$$

In the second step the landmarks are used to determine the desired value for the lengths of the bones. The bones are scaled along their longitudinal axis. The other axes are unaffected. The new end point of the bone will be the new start point of the linked bone. All linked landmarks and muscle points are adjusted with the bone length as well (see figure 5). Not only the start and end points have to be scaled, the control points must be scaled as well to make sure that the bulge of the muscle is not changed by scaling.

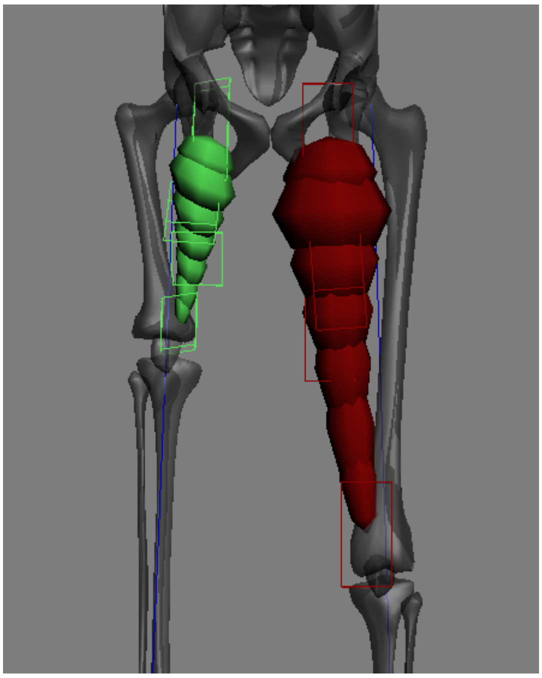

Figure 5: Scaling of Bones and Muscles (left: scaled to 50%, right: original size)

5.2 Adapting Posture

Even so the template model is already in scan position the posture has to be adapted to the posture of the scan exactly. Adapting begins in the middle of the figure using the landmarks at crotch and hips. This guarantees that the pelvis is oriented correctly. Now, all other limbs can be adjusted in the order spine, shoulder, upper arm, lower arm, wrist, head, upper leg, and lower leg, foot. In the end the landmarks of the template and the scan model have to be in the same position.

5.3 Fitting Body-Shape

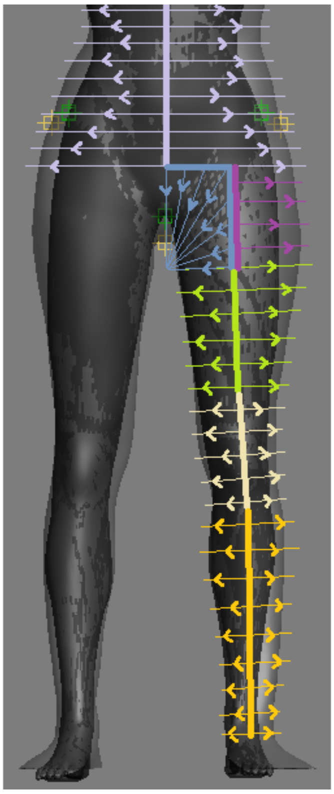

Figure 6: Segmentation of the lower body

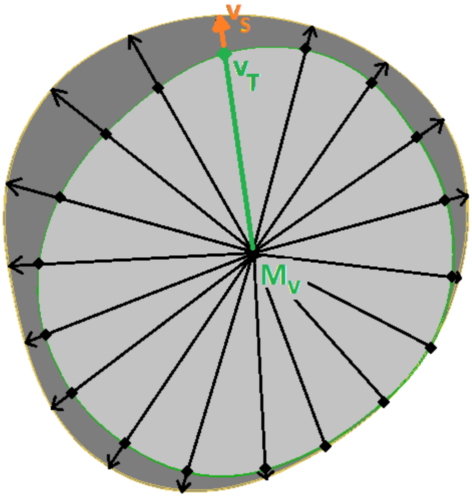

Figure 7: Moving vertices from template to scan model

To fit the body shape to the surface of the scan model, the template model has to be segmented (see figure 6). The fat lines mark the segment lines l_S, the thin lines mark the cross sections, and the arrows mark the direction of the intersection vector. For the lower body we have 11 segments: three for each leg (S_4, S_5, S_6), one for the torso (S_1) and four for the region between legs and torso (S_2, S_3). For each segment a segment line is defined automatically by using the landmarks.

For each vertex v_T of the template the corresponding cross section E_v is determined:

a) for all segments except S_2 by the normal form

$$\left(\vec{v}_T - \vec{a}\right) \cdot \vec{l}_S = 0$$

where $\vec{a}$ is an arbitrary position vector of a point $A \in E_v$, l_S is the normal of the plane and v_T is the considered vertex of the template model.

b) for segment S_2 by three points

$$\vec{a} = \vec{v}_T + s \cdot \vec{v}_{cr1} + t \cdot \vec{v}_{cr2}$$

where $\vec{a}$ is an arbitrary position vector of a point $A \in E_v$, $\vec{v}_{cr1}$ is the front crotch point, $\vec{v}_{cr2}$ is the back crotch point and v_T is the considered vertex of the template model (see figure 6).

Figure 7 shows the top view of a cross section of the right thigh, the cross section of the template model is colored in light gray, the cross section of the scan model is colored in dark gray. Intersecting the cross section with the segment line results in M_v. This point is the start point for the orientation vector. The direction is given by $\vec{M}_v - \vec{v}_T$. Intersecting the orientation vector with the surface of the scan model results in the new vertex v_S. This process is done for each vertex of the template model. It is not necessary, that v_T lies within the cross section of the scan model.

The used algorithm sets constraints to avoid folds in the new mesh matching exactly the surface of the scan model. Figure 8 shows the right leg fitted to the scan data in comparison to the left leg of the template model. The connectivity of the mesh does not change.

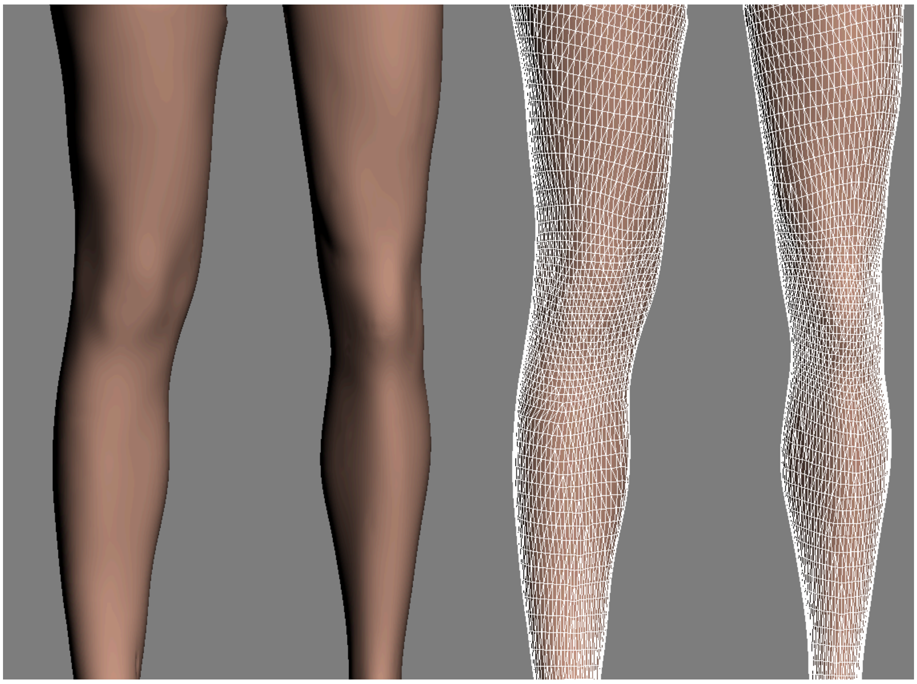

Figure 8: Fitting of the right leg (template) to scan data

5.4 Transferring Kinematic System

Because the mesh uses an identical connectivity to the template model the kinematic system can be transferred easily. There have to be made some little adjustments for the skeleton muscles and the extra bones to take care of the new volume and surface of the mesh. The skin weights cannot be transferred in form of envelopes for each bone, they have to be set explicitly to the exact skin weights used for the template (done automatically).

5.5 Transferring Postures and Movements

Loading of poses and movements for a logically unchanged bone system is a standard task and needs no specific effort.

6. Results and Further Works

We have presented a method for fast and widely automated skeleton- and muscle-driven animation of scans that is applicable for non-animators. The basis for this is our well-developed template model with a good kinematic system integrated and a process for fitting the surface to the scan data without changing the connectivity of the mesh.

The animated scan model will be only as good as the quality of the template model and the definition of landmarks on the scan model is. Our method is optimized for the classical scan posture. It is not limited to it, but reimplementation would be necessary to adopt it to other start postures.

We focused on female bodies. The process can be applied for male bodies and children as well. A new template model and kinematic system has to be defined therefore. Parts of the female body may be reused.

The different poses will be used to construct 3D patterns for close-fitting garments, to flatten and compare them. The flattened patterns can be sewn together virtually and used for dressing the scan model. The stress-strain behavior will be visualized for different fabric properties and patterns.

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