Made-to-Measure Technologies for Online Clothing Store

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1. INTRODUCTION

The Internet along with the rapidly growing power of computing has emerged as a compelling channel for sale of garments. A number of initiatives have arisen recently across the world [1][2][3], revolving around the concepts of Made-to-Measure manufacturing and shopping via the Internet. These initiatives are fueled by the current Web technologies available, providing an exciting and aesthetically pleasing interface to the general public.

However, until now such Web applications have supported only basic functions, such as viewing apparel items in 2D or 3D, combining different items together, mix and match of color and texture, sometimes with a mannequin adjusted to the shopper’s proportions. The most common problems include poor fit, bad drape, or unpleasant feel while wearing the item, or surprise as to the color of the garment. Customer dissatisfaction in any of these cases drives returns and a costly occurrence for e-tailors. In consequence, high product return rates persist, and most consumers are still either hesitant to purchase garments online or are unsatisfied with their online shopping experience [4].

In our work, we present a Web application that provides more powerful access and manipulation of garment related items to facilitate garment design, pattern derivation and sizing. A significant step in this process is the application of 3D graphics technology to help create and simulate the virtual store and we discuss various relevant research problems; the creation of body/garment, simulation of body/garment movement and online sizing. Although some authors claim that using Web 3d technologies is unlikely to be of any advantage for e-commerce by distracting customers while causing increased maintenance costs [5], efforts to bring virtual reality for online garment sales have been constantly pursued not only to obtain visually pleasing results but also to provide a high level of interactivity.

Our system supports a number of efficient and interactive operations, such as automatic adjustment of the 3D mannequin according to the shopper’s body measurement, the selection and trial of different garment items, the online fitting/resizing of the garment to the mannequin and real-time simulation of the garment movement. It is our ultimate goal to develop and integrate several key technologies into a distributed, interactive virtual clothing store, where customers can choose garments and try on 3D mannequins that are adjusted to their body measurements, and are assisted to conduct proper online purchase of apparels.

2. SYSTEM OVERVIEW

2.1. BACKGROUND AND ENABLING TECHNOLOGIES

An online clothing store designed as a Web application requires flexible manipulation, fast transmission and efficient storage of the display content. In particular, dealing with a relatively huge database of garments and the simulation of complex graphical objects, such as skin and the cloth, the most critical limitation is perhaps the real-time performance constraint. When the simulation of garment movement is performed using physics based model, due to the impossibility to achieve the real-time performance, simulation results are prerecorded in order to display the animated garment at an interactive rate [6].
Although it will simplify the online computation, it requires however to transfer for each frame the position data of each vertex constituting the visual representation of a garment, increasing the response time of the client application. In addition, expense to simulate each 3D garment item in the database is not negligible. Typically, it takes about four to twelve hours to simulate the garment movement of a one-minute sequence depending on the complexity of the 3D geometry. In our application, we choose a better alternative: the garment simulation is calculated on the fly while keeping the response time interactive.

Human body modeling and simulation is another key technology enabling the support of automated garment sizing and size selection. Since the advent of 3D image capture technology, there has been a great deal of interest in the application of this technology to the measurement of the human body. In the market, there are now also available some systems that are optimized either for extracting accurate measurements from parts of the body, or for realistic visualization for use in various fields including e-commerce applications. Cyberware Inc. [7]'s DigiSize™, for instance, was developed in a joint government project to improve and automate fitting and issuing of military clothing. They are aiming at complete and state-of-the-art solutions to age-old tape measurements and trial-and-error fitting problems.

Despite their recent efforts devoted to the use of 3D body scanners, limiting factor lies in the inability to electronically and automatically integrate body scan data to application software. Such limitations led us to consider another body modeling scheme. One important feature of the online clothing store is its ability to build a 3D mannequin according to user input measurements on various parts of the body. We perform the online construction of the 3D mannequin that satisfies the given measurements, avoiding the complication of going through the scanner and/or the time consuming process of downloading large data models. Despite the seemingly difficulties in building the whole body geometry from the limited amount of information within the real-time constraint, we show how it is made feasible through our robust modeling technique for practical applications. Moreover, with such approach, the measurements and the body motion can be modified interactively.

Figure 1 shows the system architecture. Our approach provides a minimal response time to the user, since a major part of the content to be manipulated is generated on the client side rather than on the server. Computing the body and cloth animations on the server and sending this data through Internet would generate too much traffic and would reduce the response time of the application. Thus, our solution is to move body/garment sizing as well as cloth/skin animation to the client side avoiding the download of large pre-calculated models.

2.2. THE SERVER

The online clothing store Web server consists of several databases and an online database retrieval application module for retrieving data.
**Body database:** This database contains two 3D mannequins for each gender, which we refer as generic models, plus certain statistical information that is collected from existing models through 3D shape capture technologies. This is essentially the information necessary to derive new body geometries from measurement inputs by the body/garment sizing module in the client side.

**Garment database:** A set of 3D garment models has been created for the generic models and categorized. They are available for the user to choose from the garment catalog pages. Ideally, the online clothing shop proposes a great number of different garments. Moreover, it makes easy to update the database to keep the coherence between the clothes shown on the Web application and the clothes available for sale. Therefore, this garment database is located on the server side. Upon user selection, the chosen 3D garment model is downloaded to the client. These garments are saved into virtual reality modeling language (VRML) format, a widely used format for representing 3D on the Web.

**Motion database:** The animation database contains samples of body motion data. Similarly to the garment data, selected motion data can be downloaded upon request. We obtain the motion data through the prerecording of a real person’s movement using an optical motion capture system.

**Scene database:** Graphical elements that compose the background scene are stored in VRML files.

### 2.3. THE CLIENT

Our Web client performs program execution after the executables are downloaded to the client as an ActiveX control. There are two main modules:

- The **body/garment sizing module** provides functionalities to deform the 3D mannequin from the customer’s input body size and the resize the selected garment accordingly.

- Once the static shape is completed on the 3D mannequin and the garment, the animation of the dressed mannequin is taken care of by the **real-time garment simulation module**. This approach drastically reduces the amount of data transferred from the server to the client.

### 3. BODY DATABASE

Our measurement-driven body modeling approach largely consists of a preprocessing phase and a runtime phase. The body database is designed to store the preprocessing results that are fed into the runtime module. In this section we mainly discuss the preprocessing phase by describing what measurements were used, how the generic body models are prepared, and what data is required for the runtime body/garment sizing.

#### 3.1. USE OF MEASUREMENTS

The application uses 8 primary measurements (listed in Table 1), which have been defined in sizing surveys [7] for apparel design. We assume that the users are aware of their own measurements or the measurements have been retrieved from 3D scanners or tapes.

<table>
<thead>
<tr>
<th>Body measurement</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature</td>
<td>Vertical distance between the crown of the head and the ground.</td>
</tr>
<tr>
<td>Crotch length</td>
<td>The vertical distance between the crotch level at center of body and the ground.</td>
</tr>
<tr>
<td>Arm length</td>
<td>The distance from the armscye shoulder line intersection (acromion) over the elbow to the far end of the prominent wrist bone (ulna) in line with small finger</td>
</tr>
<tr>
<td>Neck girth</td>
<td>The girth of the neck-base</td>
</tr>
<tr>
<td>Chest/Bust girth</td>
<td>Maximum circumference of the trunk measured at bust /chest height</td>
</tr>
<tr>
<td>Underbust girth</td>
<td>Horizontal girth of the body immediately below the breasts</td>
</tr>
<tr>
<td>Waist girth</td>
<td>Horizontal girth at waist height</td>
</tr>
<tr>
<td>Hip girth</td>
<td>Horizontal girth of the trunk measured at hip height</td>
</tr>
</tbody>
</table>

#### 3.2. GENERIC MODELS

Instead of constructing a new geometry for each model, we assume that the topology of the model is known in prior and shared by all resulting models. The idea behind this is to exploit the common structure of the objects we are dealing with. Aside from making the problem simpler and the modeling faster, deforming existing model to obtain a new one makes it easier to immediately animate the newly generated model.

The generic model is composed of a standard [9] human skeleton structure and a textured skin surface of approximately 6,000 vertices and 10,000 triangles. There are two models, one for each gender. The preparation of the generic models consists of three successive procedures: (1) An HANIM [9] skeleton is created and adjusted properly in relation to the body mesh. (2) The Skin attachment data is then calculated. (3) The body mesh is segmented and the whole body structure is exported into the HANIM format. The whole process is made in the 3DS Max™ environment, by using either our in-house plugin or a commercially developed plugin [10].
3.2.1 The skeleton hierarchy

The HANIM standard [9] specifies a common way of representing humanoids in VRML97. The human body consists of a number of ‘Segments’ (such as the forearm, hand and foot), which are connected to each other by ‘Joints’ (such as the elbow, wrist and ankle). The full HANIM hierarchy is composed of 94 skeleton joints and 12 skin segments including the head, hands and feet. In our application, we have chosen an HANIM Level of Articulation (LoA) 2 skeleton as shown in Figure 2(b).

3.2.2 Segmentation and exportation

The skeleton-driven deformation [12], a classical method for the basic skin deformation is perhaps the most widely used technique in 3D character skin deformation. A prerequisite of a successful skeletal-driven deformation is an appropriate attachment of the skin to the underlying skeleton. The attachment is considered as assigning for each vertex of the mesh its affecting bones and corresponding weights. To say that a vertex is “weighted” with respect to a bone means that the vertex will move as the bone is transformed in order to stay aligned with it. In our current implementation, this is done using an external application [10]. Later in the paper, the skeletal deformation is used not only for the skin simulation but also to modify the size of particular segments and the posture by applying rigid transformation on the joint.

Figure 2: Automatic segmentation of body model

Once the attachment has been defined, the work that remains is to segment skin mesh and locate each of them into the skeleton hierarchy as a proper child node of the corresponding joint. The mesh is decomposed into a collection of adjacent triangles that share the joint of highest weight, forming segment nodes of the corresponding joint nodes as shown in Figure 2(c). The model after the segmentation is ready for the exportation into an HANIM compliant human body. The attachment data is exported as XML data in the VRML file.

3.3. EXAMPLE BASED APPROACH

In this section we overview a central part of constructing the measurement-driven body models in real-time. We note that mere geometric consistency of measurements does not guarantee a reasonable appearance of the resulting body shape. Arguably, the captured body geometry of real people provides the best available resource to model and estimate correlations between measurements and the shape. Our basic idea is to exploit correlations among different measurements and between measurements and the shape of the body that are presented in the real bodies of individuals. In doing so, a robust modelling of body geometry is made possible even when only a limited amount of information is available.

Figure 3. Body modeling scheme

Figure 3 shows the workflow of the body modeling process. Two preprocessing tasks are involved. First, topological equivalence among these data sets (example models hereafter) is established such that a complete mapping can be found for each vertex in the mesh as well as the skeletal structure. Based on the prepared samples and their measurements, the second task implements interpolators that will be used to evaluate deformations necessary to obtain new models in the continuous range in the measurement space. The online execution of the body/garment sizing module, makes use of the interpolator function to deform the generic model on the fly through multi-way blending of examples.

3.3.1 Example models preparation

The initial models or examples rely on existing models or 3D shape capture technology. In addition, the correspondence is assumed to be established among the models. Each model must include the same number of vertices and connectivity in the mesh as well as the same joint hierarchy. This is performed by appropriately fitting the generic model onto each example. The detail
description of our method to obtain correspondence among example models is beyond the scope of this article. Having a predetermined topology has both theoretical and practical merits: First, it simplifies the problem by allowing a vector representation of the body geometry. Second, the skin attachment data can be reused so that all resulting models are immediately animatable. Finally, different postures of examples are easily resolved by taking only translation and scale parameters from the examples.

(a) The generic model  (b) An example  (c) After the fitting

Figure 4. Fitting of a generic model to an example.

14 models (6 male and 8 female) from 3D scanner have been used in our application. After the correspondence establishment, they are measured following the definition of Table 1 to obtain 8 primary measurements. The measured values of each, together with its joint and shape parameters (See Section 3.3.2), serve as input to the interpolators.

We consider the body geometry to have two distinct entities, namely rigid and elastic component of the body deformation. The rigid component is represented by joint parameters of a person, which will determine the global proportion of the physique. Then, shape parameters are used to express the elastic component, which, when added, depicts the detail shape of the body.

- **Joint parameters**: The joint parameters are essentially each joint’s degree of freedom (DoF). A joint has scale \((s_x, s_y, s_z)\) and translation \((t_x, t_y, t_z)\), leading to a vector of \(6N\) dimension, where \(N\) is the number of joints.

- **Shape parameters**: As shown in Figure 4, we use a set of contours to represent the detail shape of the body geometry, particularly on the torso. Note that many of the primary measurements are based on contours. The elastic deviation of the contour vertex through the fitting process from its initial position is used to represent the elastic component of the deformation.

In order for a compact representation of both parameters, we adopt PCA (Principal Component Analysis), one of the common techniques to reduce the dimensionality of data in a statistical manner. See [13] for an extensive discussion of this technique.

### 3.3.2 Interpolators construction

Once the example models are prepared, we proceed by building interpolators that will be used to evaluate deformations necessary to obtain new models by the body/garment sizing module. There are two interpolators considered: Given a particular measurement set, joint interpolators are responsible for the rigid component of the body deformation, guiding the skeleton-driven deformation to obtain the appropriate proportion of each body part. The shape interpolators deal with the elastic deformation, adding detail shape on the body. Dealing with high dimensional data and relatively small (<10) number of examples, a scattered interpolation problem best describes our problem. In consequence, both joint and shape interpolators are implemented as functions of the eight primary measurements by using radial basis function (RBF).

- **Joint interpolators**: The joint interpolators transform a measurement vector onto a set of joint parameters. Measurement and joint parameters pairs extracted from the examples serve as interpolation nodes. There are \(6N\) (\(N\) being the number of principal components used, 5 in our case) interpolators, which are responsible for one of the 6 DoF of the joints.

- **Shape interpolators**: While joint parameters are used for describing the rigid component of the body geometry, residual component is represented by shape parameters. Similar to the joint interpolators, we build shape interpolators to interpolate the shape of each contour. There exist two groups of shape interpolators: (1) **Primary interpolators** transform a vector from the measurement space to a feature shape space, which is composed of the shape vector of primary contours. (2) **Auxiliary interpolators** are responsible for the transformation from the feature space to non-feature shape space. With the latter, displacements of auxiliary contours (or non-features) are evaluated as a function of those of primary contours (features). While the primary interpolators exploit the size to shape correlations that exist in the sample bodies, the auxiliary interpolators are for the shape-to-shape correlations, both contributing to the estimation of realistic shapes given a measurement set.

### 3.3.3 Interpolator exportation

Once the interpolators have been generated, the measurement space can be quickly explored to evaluate the rigid and elastic component of the deformation, allowing run-time generation of customized 3D body model. Implemented as RBF, each interpolator is described by its interpolation nodes and their corresponding weights. To speedup the runtime
evaluation, the basis function is implemented by using a table lookup.

4. GARMENT DATABASE

A set of garments is calculated for the generic model. The garment database is composed of these garments. For creating clothes usable in the online clothing store, designers must draw the patterns, pre-process the garments and export them into VRML format. Several authoring tools have been developed to assist designers in their work.

4.1. DESIGN OF GARMENTS

The garment creation is done using our in-house software [12]. The garment designer is assisted in drawing 2D patterns and defining seaming lines on the borders of the garment patterns, referring to the polygon edges that are to be joined during the garment construction process as shown in Figure 5(a). The patterns are then tessellated into a triangular mesh and are placed around the 3D virtual body (Figure 5 (b)). Next, the initial shape of the garment is computed through a collision response, as illustrated in Figure 5 (c). The shape of the body model guides the surface of the cloth as a result of the collision response. Since the garment sizing is handled online by the body/garment sizing module, only one simulation is necessary for each garment item to be prepared on the generic model.

4.2. GARMENT PREPROCESSING

Simulating garments in real-time requires drastic simplifications of the simulation process to be carried out, possibly at the expense of mechanical and geometrical accuracy. Our approach [15] is based on a hybrid method where the cloth is segmented into various sections where different algorithms are applied. When observing a garment worn on a moving character, we notice that the movement of the garment can be classified into several categories depending on how the garment is laid on, whether it sticks to, or flows on, the body surface. For instance, a tight pair of trousers will mainly follow the movement of the legs, whilst a skirt will flow around the legs. Thus, we segment the cloth into three layers that we define as follows:

- **Layer 1: "Stretch clothes"
  Garment regions that stick to the body with a constant offset. In this case, the cloth follows exactly the movement of the underlying skin surface.

- **Layer 2: "Loose clothes"
  Garment regions that move within a certain distance to the body surface are placed in another category. The best examples are shirtsleeves. The assumption in this case is that the cloth surface always collides with the same skin surface and its movement is mainly perpendicular to the body surface.

- **Layer 3: "Floating cloth"
  Garment regions that flow around the body. The movement of the cloth does not follow exactly the movement of the body. Collisions are not predictable; for a long skirt, for instance, the left side of the skirt may collide with the right leg during animation.

These three categories are animated using three different cloth layers. The idea behind the proposed method is to avoid the heavy calculation of physical deformation and of collision detection wherever possible, i.e. where collision detection is not necessary. The main interest of our approach is to pre-process the target cloth and body model so that they are efficiently computable during runtime. The garments are divided into a set of segments and the associated simulation method is defined for each.

4.2.1 Computing cloth attachment data

Defining attachment data is one step of the pre-processing stage to be done on the garments. As stated in the previous section, the cloth deformation method makes use of the shape of the underlying skin. Each vertex of the garment mesh is associated to the closest triangle, edge or vertex of the skin mesh.

![Figure 5: The making of garments](image)

![Figure 6: Mapping of attachment information](image)

In the Figure 6, the garment vertex C is in collision with the skin triangle $S_1S_2S_3$. We define C’ as the closest vertex to C located on the triangle $S_1S_2S_3$. We then define the barycentric coordinates of C’ with $S_1$, $S_2$ and...
S3. These barycentric coordinates are later used for cloth simulation and sizing. They provide an easy way to compute the rest shape of the garments by using the location of the skin vertices.

4.2.2 Segmentation

From the garment in its rest shape on the initial body, the distance between the garment and the skin surface is used to determine to which category the cloth triangles belong. Associated with each segment are distances from the skin surface that are used to determine the category. Each segment falls into one of three categories: tight, loose and floating clothes. Cloth vertices that are located closely to the skin surface belong to the first or the second layer. Cloth vertices that do not collide with any skin surface belong to the third layer as shown in Figure 7 (a).

![Figure 7: Segmentation of garments.](image)

4.2.3 Exportation

Once segmented, 3D cloth models and the associated data can be exported to VRML format for use in the online clothing store. These models are located on the server, allowing easy update and maintenance.

5. MOTION DATABASE

What are probably the major criteria in garment animation is of much less concern in body animation. Commercially available motion capture systems offer a relatively easy way of recording a human performer’s movement. Because the generic models we use are described in HANIM standard, the animation data has been converted such that it is immediately applicable to HANIM models. The converter first computes the correspondence between the two skeleton hierarchies (one from the motion capture system and the other from the HANIM) and performs the transformation on each joint angle for each frame of animation in order to resolve the difference in their stand-by posture.

The converted animation data is exported in VRML format using the Interpolator node and can be applied to the HANIM body model in a frame-by-frame basis. The database is made of several typical motions that people do when trying clothes – walking and turning to mention a few.

6. INTEGRATION OF THE CLIENT

The client application is not only involved in the visualization of garments, but also used for the calculation of the cloth and body deformation. As shown in Figure 8, the architecture of the client makes use of three different layers for the implementation: C++, JavaScript and HTML.

![Figure 8: Overview of the Client Architecture](image)

6.1. THE ACTIVEX CONTROL

Modules for real-time animation and visualization have been developed in C++ and integrated into an ActiveX control. ActiveX controls are components that can be embedded within Web browsers like Internet Explorer. Because they can be written in any language, they offer the best performance for time-critical applications. Another advantage of ActiveX controls is that their installation on the client machine is transparent to the user. They are automatically downloaded and installed at the first access to the Web page.

Our ActiveX control is composed of several modules: the FTP client for downloading data from the server, the VRML loader that is in charge of loading the data into the scene manager, the skeleton animation player for animating the mannequin skeleton, the body/cloth sizing module for fitting the body and clothes to the user measurements, the skin and cloth deformation module for real-time animation, and the 3D viewer for visualization of the scene.

6.2. JAVASCRIPT AND HTML PAGES

JavaScript together with HTML are used for the implementation of the graphical user interface. They provide a good solution for user interaction.
allows complex functionalities such as keeping trace of the user choices, widget managements, and sending the user defined parameters to the ActiveX Control. Figure 9 shows the Web page where the user enters the body measurements and visualizes the animation of the 3D mannequin.

7. BODY/GARMENT SIZING MODULE

The main task of body/garment sizing module is to manage the proper sizing of the 3D mannequin in a VRML scene. As described above, it makes use of the generic model and the interpolators to evaluate the joint and shape parameters to deform the generic model. It first deforms the body model by applying the evaluated parameters from the interpolators as a function of the measurement input. The garments are then deformed accordingly such that they fit to the deformed body.

7.1. BODY SIZING

Upon the measurement values or a specific location in the measurement space chosen by the application at runtime, the interpolator evaluates the necessary deformation by efficiently blending the examples with known measurements to produce an interpolated shape.

7.1.1 Contour warping

Given the new set of measurements, the location in the measurement space is determined. With this vector as input, the joint parameters are evaluated from the joint interpolators for each joint in the skeleton. Figure 10b shows the model after the joint parameters are applied to the model shown in Figure 10a. Similarly, the shape interpolators determine the shape of the primary and the auxiliary contours consecutively and deform them by adding the evaluated elastic constitute as shown in Figure 10c.

![Figure 9: ActiveX viewer and HTML/JavaScript user interface](image)

![Figure 10: Skin deformation through interpolation](image)

7.1.2 Mesh deformation

In order to compute a skin surface which smoothly interpolates between deformed contours, we use once more the scattered data interpolation technique. For each point $p_i$ on the skin mesh, the final location is given by

$$p'_i = p_i + W(p_i),$$  \hspace{1cm} (1)

where $W = (s_x, s_y, s_z)$ denotes the deformation function and $W(p_i) = \Delta p'_i, \Delta p'_b, \Delta p'_h$. For $n$ points $p_1, p_2, ..., p_n$ of the contour set, we have $W(p_i)$’s from the shape interpolators. Then the coefficients of the Gaussian function interpolants $s_x, s_y, s_z$ can be found by solving a linear system of $3n$ equations:

$$\begin{align*}
    s_x(p_i) &= \sum \omega_i \cdot \Phi(\|p - p_i\|), \\
    s_y(p_i) &= \sum \omega_i \cdot \Phi(\|p - p_i\|), \\
    s_z(p_i) &= \sum \omega_i \cdot \Phi(\|p - p_i\|),
\end{align*}$$  \hspace{1cm} (2)
Once the interpolators have been calculated, we deform the mesh by displacing all points on the mesh according to the resulting values.

7.1.3 Refinement

Some joints are directly related to the input (stature, the crotch length and the arm length) measurements and the evaluated joint parameters from the interpolators need to be adjusted accordingly. The refinement phase of our approach measures the model from the interpolators and adjusts the skeleton in order to assure the user specified measurement constraints on the model.

7.2. GARMENT SIZING

After the body model is properly deformed from the given measurements, the garment-sizing module modifies the garments in a way that they fit to this new body. As explained earlier, the cloth mesh is segmented into three layers, two layers where the cloth vertices are attached to the body surface and one layer where the garments move freely. Thanks to the cloth attachment data (Figure 6), the position of vertices belonging to the first two layers are easily computed from the position of the underlying skin vertices weighted with the barycentric coordinates. Cloth vertices on the these two layers follow the skin surface, even in the case where the skin is deformed by the body-sizing module. For the sizing of garments belonging to the third layer such as skirts or dresses, the diameter and the length of legs are calculated in the body deformation module. The length and the width of the garments are modified accordingly to the new measurements of the legs. Figure 11 shows the body/garment sizing results.

8. SKIN/GARMENT SIMULATION MODULE

After generating the dressed body according to the user measurements, the motion data applied to the HANIM skeleton drives the skin and the cloth deformation. This section addresses the computation of the real-time simulation of bodies and clothes according to the animation of the underlying skeleton.

8.1. JOINT-DRIVEN DEFORMATION OF SKIN

Skeletal driven deformation technique, introduced in 3.2.2 is used. At each frame of the animation, the position of vertices is calculated using the weight values and the transformation matrix of the joints. These weight values are also used to compute the normal of the mesh surface. The movement of vertices that belong to a single joint is not calculated but automatically moved as they are attached to the joint. Duplicated vertices that are on the boundaries have the same position as they share the same attachment information. Thus, the boundaries among segments are not visible. The result is a segmented body that appears as a seamless body in the rendering view port. This method combines the speed of the deformation of segmented bodies with the visual quality of seamless bodies.

8.2. GARMENT SIMULATION

In [15], techniques for real-time clothes simulation are proposed. Garment vertices are animated with three different methods, depending on which layer they belong that is defined during the pre-processing stage.
8.2.1 Layer 1

Tight clothes in Layer 1 follow the deformation of the underlying skin. These deformations are calculated thanks to the mapping of the attachment data of the skin to the garment surface.

8.2.2 Layer 2

For Layer 2 that is composed of loose clothes, the relative movements of clothes to the skin remain relatively small, keeping a certain distance from the skin surface. Consider the movement of sleeve in relation with the arm: for a certain region of the garment, the collision area falls within a fixed region of the skin surface during simulation. With this in mind, the scope of the collision detection can be severely limited. A basic assumption made is that the movement of the garment largely depends on that of the underlying skin and yet it should not follow the skin surface rigidly. It is necessary to simulate the local displacement of the garment from the skin surface.

Two different methods have been developed, one for cloth deformation on the limbs (trousers and sleeves), the other one for the deformation of cloth on the trunk. Cloth vertices on the limbs are enclosed in half spheres that are attached to the skin surface. Vertices inside these spheres are displaced with the equation of the rigid body motion. A function defines the diameter of the spheres depending on the relative position of the cloth vertex to the normal of the skin surface. Cloth vertices located on the trunk are animated with a rough mesh. This rough mesh is animated with a physic-based method. The cloth mesh is deformed with the FFD method using the position of the vertices on the rough mesh.

8.2.3 Layer 3

Layer 3 is composed of vertices that freely float around the body. This will take care of cases, such as a large skirt floating around the legs. Any part on this skirt can collide with any part of the leg. The simulation of this layer uses a classical approach with particle system and collision avoidance.

9. RESULTS AND DISCUSSION

Figure 13 shows the main graphical user interface (GUI).

After user authentication, the communication is first established; the ActiveX control is downloaded if it has not already been installed on the machine. Initialization of the control is executed, including the download of the data for the body/garment sizing module. The visitor to the online virtual store follows several successive steps provided:

1. After the selection of the garment item through the 2D garment catalog, the user selection is passed to the ActiveX control through JavaScript functions.

2. The requested garments and motion data are downloaded and are then loaded into the scene using the VRML loader.

3. The user continues to the body measurements page containing a number of fields that are adjustable.
4. Finally, a trigger action starts the execution of real-time simulation. While the skeleton animation player updates the angle values of the mannequin’s skeleton, the skin and clothes are deformed accordingly.

Figure 14: The catalog window

The time needed for the simulation is obviously linked to the complexity of the body and the garment model. The table below shows the average size of the different data to be downloaded for a simulation sequence.

<table>
<thead>
<tr>
<th>Data</th>
<th>Average size in Mbytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body data with generic textured model</td>
<td>2.0</td>
</tr>
<tr>
<td>(8000 polygons)</td>
<td></td>
</tr>
<tr>
<td>Motion data (Duration 10 sec.)</td>
<td>0.2</td>
</tr>
<tr>
<td>Garments with textures</td>
<td>1</td>
</tr>
<tr>
<td>(4000 polygons)</td>
<td></td>
</tr>
<tr>
<td>Scene with textures</td>
<td>1</td>
</tr>
<tr>
<td>(1000 polygons)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Average size of downloaded data

The biggest amount of data to be downloaded is the body database. Fortunately, this database needs to be downloaded only once at the initialization stage of the ActiveX control. Other data needs to be downloaded every time the user changes the garments and/or motion data. The frame rate of the real-time animation of the mannequin in the ActiveX control is about 20 to 30 frames per second. See [15] for a further discussion of the performance of the body/garment deformation module.

10. CONCLUSION AND FUTURE DIRECTIONS

In our work, various research problems have been solved in order to build a framework for the online clothing store. Design decisions, as well as related issues on creating, simulating and fitting 3D garments and human body models have been discussed. The process of preparing various data components has matured, making it feasible to efficiently handle the creation of graphical contents, which are immediately usable for interactive visualization on the Internet. The bodies and the garments created with our approach correspond to real body measurements at the critical locations defined for the garment design. In particular, methods for efficient handling of the online body modeling, garment selection, fitting and simulation have been developed and integrated into Web components, optimized for the execution on the Internet. Finally, we set up an interactive and realistic virtual clothing store, where visitors can choose among many different types of garments and visualize them on animated mannequins based on their measurements.

Nevertheless, there are still rooms for improvements. The sizing works only for both the garment and the body and the simulation of differently sized garments on the same body remains as future work. We also plan to enhance the input parameters to model the 3D mannequin such that it allows the best possible correspondence to a particular individual.

The virtual Try-On can be visited at http://virtual-try-on.miralab.unige.ch.

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REFERENCE


