Automatic Modeling of Virtual Humans and Body Clothing

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Abstract

Highly realistic virtual human models are rapidly becoming commonplace in computer graphics. These models, often represented by complex shape and requiring labor-intensive process, challenge the problem of automatic modeling. This paper studies the problem and solutions to automatic modeling of animatable virtual humans. Methods for capturing the shape of real people, parameterization techniques for modeling static shape (the variety of human body shapes) and dynamic shape (how the body shape changes as it moves) of virtual humans are classified, summarized and compared. Finally, methods for clothed virtual humans are reviewed.

Keywords: Human body modeling, animatable models, automatic methods.

1. Introduction

Human body modeling and animation have been one of the most difficult tasks encountered by animators. In particular, realistic human body modeling requires an accurate geometric surface throughout the simulation.

At this time, a variety of human body modeling methodologies are available, that can be classified into three major categories: creative, reconstructive, and interpolated. Anatomically based modelers, such as Scheepers et al [27], Shen and Thalmann [31] and Wilhelms and Van Gelder [33] fall into the former approach. They observe that the models should mimic actual components of the body and their models consist of multi-layers for simulating individual muscles, bones and tissues. While allowing for an interactive design, they however require considerable user intervention and thus suffer from a relatively slow production time and a lack of efficient control facilities.

Lately, much work has been devoted to the reconstructive approach to build 3D geometry of human automatically by capturing existing shape. Some of them rely on stereo [11], structured light [23], or 3D scanners [6]. Some systems use 2D images either from video sequences [13] or from photos [19][15]. While they are effective and visually convincing, one limiting factor of these techniques lies in that they hardly give any control to the user; i.e., it is very difficult to automatically modify resulting models to different shapes as the user intends.

The third major category, interpolated modeling, uses sets of example models with an interpolation scheme to construct new models. Because interpolation provides a way to leverage existing models to generate new ones with a high level of control in an interactive time, it has gained growing popularity in various graphical objects including human models.

This paper reviews automatic modeling techniques for animatable virtual humans, primarily for real-time applications. We focus our study on body modeling which are readily animatable. Model-based reconstructive methods and interpolated methods are discussed in detail, because anatomical models are more designated to the interactive design.

This paper is organized as follows: First we look for methods for shape capture of real people (Section 2). Then we review methods for modeling the variety of human body shapes in Section 3. After studying methods for dynamic shape change as the body moves in Section 4, we continue in Section 5 to the methods for dealing with dressed humans. We conclude the paper in Section 6.

2. Shape capture

Since the advent of 3D image capture technology, there has been a great deal of interest in the application of that technology to the measurement of the human body. In the market, there are now available several systems that are optimized either for extracting accurate measurements from parts of the body, or for realistic visualization for use in games, virtual environments and, lately, e-commerce applications [8].

For many years, the goal has been to develop techniques to convert the scanned data into complete, readily animatable models. Apart from solving the classical problems such as the hole filling and noise reduction, the internal skeleton hierarchy should be appropriately estimated in order to make them move. Accordingly, several approaches have been under active development to endow semantic structure to the scan data. Dekker et al [10] have used a series of meaningful anatomical assumptions in order to optimize, clean and segment data from a Hamamatsu whole body range scanner in order to generate quad mesh representations of human bodies and build applications for the clothing industry (see Figure 1).

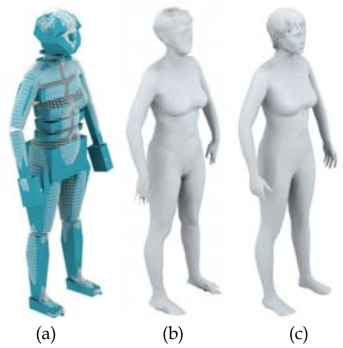

Figure 2. Conformation of a template model (a) onto a scanned data (b) [29]. The template after the conformation is shown in (c).

Ju and others [16] introduce methods to automatically segment the scan model to conform it to an animatable model.

Figure 1. After a scanned data (left) is segmented (middle) for an estimation of the skeleton structure, the posture can be modified (right) [10].

Allen et al [1] proposed an optimization technique for estimating poses and kinematics of the human body scans. A template model is used, which is equipped with the skeleton hierarchy and the skin mesh with markers placed on it. By finding the DoF that minimizes the difference marker position, the pose and kinematics of the scan could be found. Once the global proportion of the physique is captured, the displacement map is added by ray casting. Holes are filled by interpolating the rays.

Seo et al [29] adopts similar optimization technique based on manually selected feature points are presented. There are two main phases of the algorithm: the skeleton fitting and the fine refinement. The skeleton fitting phase finds the linear approximation (posture and proportion) of the scanned model by conforming the template model to the scanned data through skeleton-driven deformation. Based on the feature points, the most likely joint parameters are found that minimize the distance of corresponding feature locations. The fine refinement phase then iteratively improves the fitting accuracy by minimizing the shape difference between the template and the scan model. The found shape difference is saved into the displacement map of the target scan model. A conformation result on a female scan data is shown in Figure 2.

It is only recently that it has become a popular area the development of technologies especially for human body modeling. To recover the degrees of freedom associated with the shape and motion of a moving human body, most of the exiting approaches introduce simplifications by using a model-based approach. Kakadiaris et al, in [17], use 2D images from three mutually orthogonal views to fit a deformable model to approximate the different body size of subjects. The model then can be segmented to different body parts as the subject moves. Plaenkers et al [25] also use video cameras with stereo pair for the model acquisition of body part. A person’s movements such as walking or raising arms are recorded to several video sequences and the program automatically extracts range information and tracks outline of body. The problem to be solved is twofold: First robustly extract silhouette information from the images; second fit the reference models to the extracted information. The data was used to instantiated the models and the models, augmented by our knowledge about human body and its possible range of motions, are in turn used to constrain the feature extraction. They focus however more on the tracking of movement and the extraction of a subject’s model is considered as the initial part of a tracking process.

Recently, more sophisticated models were introduced with and they limit their aims to the construction of realistic human model. Recent work of Hilton et al [14] involves the extraction of body silhouettes from a number of 2D views (front, side and back) and the subsequent deformation of a 3D template to fit the silhouettes. The 3D views are then mapped as texture onto the deformed model to enhance realism (see Figure 3). Similarly, Lee et al [19] proposed a feature-based approach where silhouette information from three orthogonal images is used to deform a generic model to produce personalized animatable model (see Figure 4).

Figure 3. Image-based shape capture by Hilton et al[15]. (up) Input images; (down) Reconstructed model.

Figure 4. Image-based shape capture by Lee et al [19]. (up) Input images; (down) Reconstructed model.

Based on adding details or features to an existing generic model, these approaches concern mainly the individualized shape and visual realism using a high quality textures. While they are effective and visually convincing in the cloning aspect, these approaches hardly give any control to the user; i.e., it is very difficult to modify these meshes to a different shape as the user intends. These approaches have the drawback that they must deal with special cases using ad hoc techniques.

3. Static shape

A common problem in human modeling is how to systematically model the variety of human body shapes. In most cases, modifying existing model, variously named as reference, generic or template, tends to be popular due to the expenses of recovering 3D geometry.

Automatically modifying shapes is desirable for at least two reasons. Firstly, it is often the case that we want to modify shapes to meet new needs or requirements. In a garment application, for example, we might want to create a 3D body model in a way that it satisfies a number of measurement constraints with minimum user intervention, and in an interactive runtime setting. Secondly, automatic modification makes it easy to avoid redundancy in a crowd. Without having to create or reconstruct each individual, one can obtain crowds by blending of existing models, for instance.

In this section, we review several techniques that automate this task.

3.1. Anthropometric models

Anthropometry, the biological science of human body measurement, systematically studies human variability in faces and bodies. Systematic collection of anthropometric measurements has made possible a variety of statistical investigations of groups of subjects, which provides useful information for the design of products such as clothing, footwear, safety equipment, furniture, vehicles and any other objects with which people interact. Since anthropometry was first introduced in computer graphics [12], a number of researchers have investigated the application of anthropometric data in an automatic creation of virtual humans. Spreadsheet Anthropometry Scaling System (SASS) presented by Azula et al. enables the user to create properly scaled human models that can be manipulated in their animation system 'Jack' [3] (See Figure 5). The system creates a standardized human model based on a given statistically processed population data or alternatively, a given person's dimension can be directly used in the creation of a virtual human model. In the former case, it automatically generates dimensions of each segment of a human figure based upon population data supplied as input. Their initial virtual human was composed of thirty-one segments, of which twenty-four had a geometrical representation. For each segment or body structure with geometrical representation, three measurements were considered, namely the segment length, width, and depth or thickness. Measurements were compiled from the NASA Man-Systems Integration Manual [24] and the Anthropometry Source Book [23]. The desired dimension was primarily implemented by rigid scale of each component, although they showed later the extension of the system equipped with partially deformable models. Later Seo et al's paper [30] reported a similar approach, but with face models incorporated.

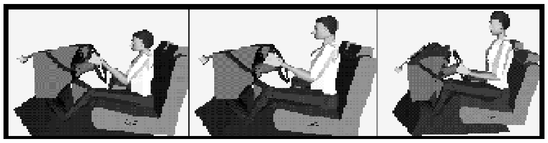

Figure 5. Anthropometric human models by Azuola et al [3].

More recently, DeCarlo et al [9] have shown that the problem of generating face geometries can be reduced to that of generating sets of anthropometric measurements by adopting variational modelling technique. The underlying idea is to generate a shape that shares, as much as possible, the important properties of a prototype face and yet still respect a given set of anthropometric measurements. They cast the problem as a constrained optimization: anthropometric measurements are treated as constrains, and the remainder of the face is determined by optimizing an objective function on the surface. A variety of faces are then automatically generated for a particular population. This is an interesting approach that, unfortunately, is slow in creation time (approximately one minute per each face) owing to the nature of variation modeling. Also, the shape remains as a passive constitute as the prototype shape is conformed to satisfy the measurement constraints while 'fairness', i.e. smoothness of the shape is being maximized. Therefore, every desirable facial feature has to be explicitly specified as a constraint in order to obtain realistic shape in the resulting model that are observable in real faces, such as hooked nose or double chin.

3.2. Interpolation techniques

In literature, a considerable amount of work has been undertaken with respect to editing existing models and blending between more than two examples to generate new ones. Although it is domain independent, the interpolation techniques or example-based approaches have been intensively used for parameterized motion blending to leverage existing motion data. Rose et al.'s paper "Verbs and Adverbs" [26] has shown results in this area using radial basis functions (RBF). Each example of motion is manually annotated with a set of adverb values, such as happy, angry, tired, etc. After normalization, each annotated motion is used to form an adverb and verb spaces using scattered data interpolation. Once the continuous range spaces are formulated, at any point in the adverb space, a corresponding motion is derived through RBF interpolation of example motions.

Sloan et al [32] have shown the application of similar technique in generation of face models. Using a number of example face models obtained from image based capture, they have shown interactive blending results with control parameters such as gender and age.

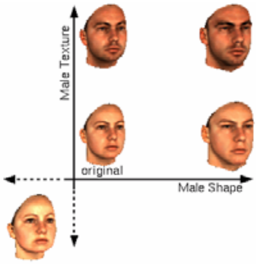

Figure 6. Manipulation of a face model by facial attributes [5].

More recently, novel interpolation methods that start with range scan data and use data interpolation to generate controllable diversity of appearance in human face and body models have been introduced. Arguably, the captured geometry of real people provides the best available resource to model and estimate correlations between measurements and the shape. In works with similar goals but applied to face models, other researchers [5] have introduced a 'morphable face model' for manipulating an existing model according to changes in certain facial attributes. New faces are modeled by forming linear combinations of the prototypes that are collected from 200 scanned face models. Manual assignment of attributes is used to define shape and texture vectors that, when added to or subtracted from a face, will manipulate a specific attribute (see Figure 6).

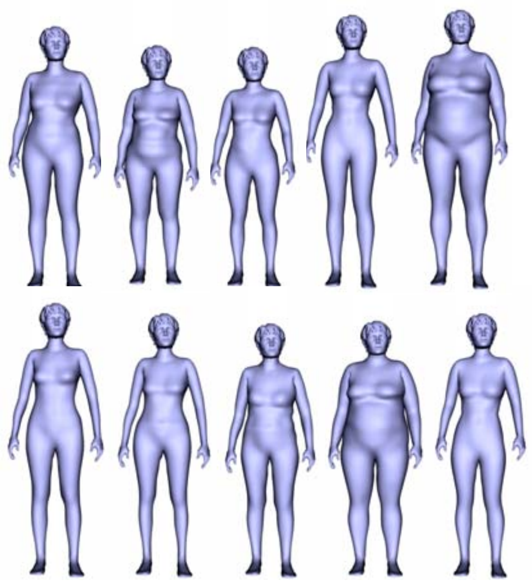

Figure 7. Various body models generated by controlling sizing parameters [29].

The automatic modeling approach introduced by Seo and Magnenat-Thalmann [29] is aimed at realistic human models whose sizes controllable by a number of anthropometric parameters. Instead of statistically analyzed form of anthropometric data, they make directly use of captured sizes and shapes of real people from range scanners to determine the shape in relation with the given measurements. The body geometry is represented as a vector of fixed size (i.e. the topology is known in a priori) by conforming the template model onto each scanned models. A compact vector representation was adopted by using principal component analysis (PCA). A new desired physique is obtained by deformation of the template model, which is considered to have two distinct entities – rigid and elastic deformation. The rigid deformation is represented by the corresponding joint parameters, which will determine the linear approximation of the physique. The elastic deformation is essentially vertex displacements, which, when added to the rigid deformation, depicts the detail shape of the body. Using the prepared dataset from scanners, interpolators are formulated for both deformations. Given a new arbitrary set of measurements at runtime, the joint parameters as well as the displacements to be applied on the template model are evaluated from the interpolators. And since an individual can simply be modeled by providing a number of parameters to the system, modeling a population is reduced to the problem of automatically generating a parameter set. The resulting models as shown in Figure 7 exhibit a visual fidelity, and the performance and robustness of the implementation.

Recently, Seo et al [28] have shown that the modification of an individual model could be driven by statistics that are compiled from the example models (Figure 8). Regression models are built upon the female scan database, using shape parameters like fat percentage as estimators, and each component of the body vector as response variables. In order to avoid erroneous estimation arising from relatively small and skewed dataset, sample calibration is preceded. In cases where tall-slim and short-overweight bodies are overrepresented in the database, for instance, weights for each sample are determined so that the linear function that maps the height to the fat percentage has the slope 0. All resulting models remain readily animatable through recalculation of the initial skin attachment.

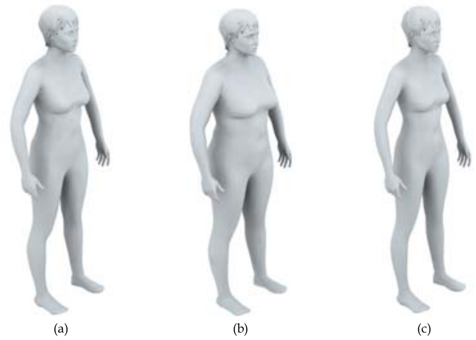

Figure 8. Variations of a body model according to fat percentage [28]: (a) original model; (b) modification of the physique (fat percent 38%); (c) modification of the physique (fat percent 22%).

Allen et al [2] have shown similar results but with manipulation of several control parameters simultaneously, by learning a linear mapping from the database models. Once the correspondence is established for all example models, a mapping function was found by solving for a mapping transformation that maps the body feature, such as height and weight, onto the orthogonal body space that has been formed by PCA (see Figure 9).

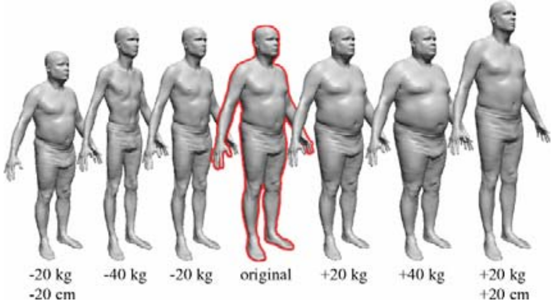

Figure 9. Variations of a body model by modifying the height and the weight [2].

4. Dynamic shape

Modeling of how the body changes shape as it moves has been a long sought problem in character animation. In this section, we review methods for systematically deforming the skin shape during the animation.

4.1. Skeleton driven deformation (SDD)

The skeleton-driven deformation, a classical method for the basic skin deformation is perhaps the most widely used technique in 3D character animation. In research literature, an early version was presented by Magnenat-Thalmann et al [21], who introduced the concept of Joint-dependent Local Deformation (JLD) operators to smoothly deform the skin surface. This technique has been given various names such as Sub-Space Deformation (SSD), linear blend skinning, or smooth skinning. This method works first by assigning a set of joints with weights to each vertex in the character. The location of a vertex is then calculated by a weighted combination of the transformation of the influencing joints as shown on the equation 1.

$$P_v = \sum_i w_i (M_i \cdot M_{i,Dress}^{-1} \cdot P_{Dress}) \qquad (1)$$

The skeletal deformation makes use of an initial character pose, namely dress pose, where $M_{i,Dress}^{-1}$, the transformation matrix of i^{th} influencing joint and P_{Dress} the position of the vertex are defined. While this method provides fast results and is compact in memory, its drawbacks are the undesirable deformation artifacts in case of important variation of joint angles among the influencing joints.

4.2. Overcoming the problems with skeleton driven deformation

Several attempts have been made to overcome the limitation of geometric skin deformation by using examples of varying postures and blending them during animation. Aimed mostly at real-time applications, these example-based methods essentially seek for solutions to efficiently leverage realistic shapes that come either from captured skin shape of real people, physically based simulation results, or sculpted by skilled designers.

Pose space deformation [20] approaches the problem by using artistically sculpted skin surfaces of varying posture and blending them during animation. Each vertex on the skin surface is associated with a linear combination of radial basis functions that compute its position given the pose of the moving character. These functions are formed by using the example pairs – the poses of the character, and the vertex positions that comprise skin surface. Two deformation results of a bending arm, one by PSD and another by the classical skeleton driven deformation, are comparatively illustrated in Figure 10. More recently, Kry et al [18] proposed an extension of that technique by using principal component analysis (PCA), allowing for optimal reduction of the data and thus faster deformation.

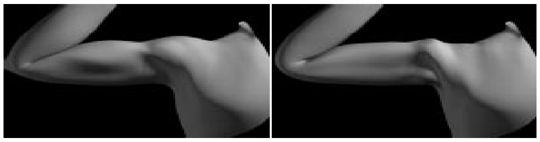

Figure 10. Pose space deformation (left) result compared to the skeleton driven deformation (right) [20].

Sloan et al [32] have shown similar results using RBF for blending the arm models (see Figure 11). Their contribution lies in that they make use of equivalent of cardinal basis function. The blending functions are obtained by solving the linear system per example rather than per degree of freedom, which potentially is of a large number, thus resulting in an improved performance.

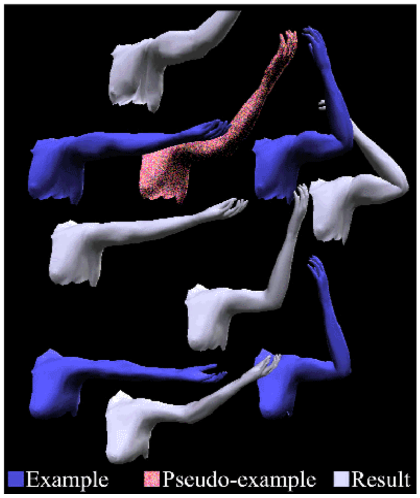

Figure 11. Example based skin deformation by Sloan et al [32].

Figure 12. Example based skin deformation by Allen et al [1].

Allen et al [1] present yet another example-based method for creating realistic skeleton-driven deformation (see Figure 12). Unlike previously published works, however, they start from an unorganized scan data instead of using existing models that have been sculpted by artists. After the correspondence is established among the dataset through a feature-based optimization on a template model followed by a refitting step, they build blending function based on the pose, using *k*-nearest-neighbors interpolation. Additionally, they build functions for combining subparts of the body, allowing for blending several datasets of different body parts like arms, shoulder and torso.

More recently, Mohr et al [22] have shown the extension of the SDD by introducing pseudo joints. The skeleton hierarchy is completed with extra joints inserted between existing ones to reduce the dissimilarity between two consecutive joints. These extra joints can also be used to simulate some nonlinear body deformation effects such as muscle bulges. Once all the extra joints have been defined, they use a fitting procedure to set the skinning parameters of these joints. The weights and the dress position of the vertices are defined by a linear regression so that the resulting skin surface fits to example body shape designed by artists. Having weights well defined, those examples could be discarded during the runtime.

5. Dressed virtual models

Recent years have witnessed the increasing number of modeling simulation techniques developed on dressed virtual humans. In this section we discuss several cloth modeling and simulation methods that are closely related to the body deformation and animation.

5.1. Garment modelling

Despite several attempts to capture and model the appearance and the behavior of 3D cloth models automatically [4][14], garment models worn by virtual models today come mostly from an interactive process. In works presented by Cordier et al [5][7], the garments worn on a 3D body model are automatically resized as the body changes its dimension (See Figure 14). They first attach the cloth mesh to the body surface by defining attachment data of the garment mesh to the skin surface. 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. In Figure 13, the garment vertex C is in collision with the skin triangle $S_1S_2S_3$. C' is defined as the closest vertex to C located on the triangle $S_1S_2S_3$. The barycentric coordinates of C' is then with S_1, S_2 and S_3.

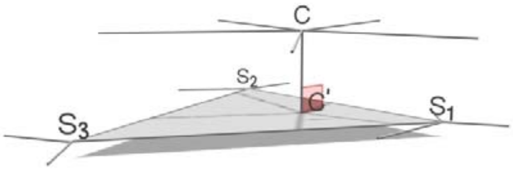

Figure 13. Mapping of attachment information [7].

These barycentric coordinates provide an easy way to compute the rest shape of the garments by using the location of the skin vertices. For every position of the triangle $S_1S_2S_3$, the position of the cloth vertex can easily computed. The association between the original body and the garment permits to smoothly interpolate the garment so that the garment remains appropriately worn on the virtual body.

5.2. Real-time garment simulation

Extensive research has been carried out in cloth simulation. Several of them have focused on the quality of garment simulation, where constraint of real-time was not a priority. Their aim was to develop a physics-based method that is able to simulate the dynamics of cloth independent of its use whether as clothing or other situations like in furnishing tablecloth. They integrated complex collision detection and they were able to simulate the physical behavior of garments [34][35][37].

Other research has focused on the real-time aspect of the animation of deformable objects using physical simulation. Baraff et al [38][36] have used the Implicit Euler Integration method to compute the cloth simulation. They stated that the bottleneck of fast cloth simulation is the fact that the time-step must to be small in order to avoid instability. They described a method that can stably take large time steps, suggesting the possibility of real-time animation of simple objects.

Meyer et al [39] and Desbrun et al [40] have used a hybrid explicit/implicit integration algorithm to animate real-time clothes, integrated with this is a voxel-based collision detection algorithm.

Other research has focused on the collision detection, stating that it is one of the bottlenecks to real-time animation. Vassilev et al [41] proposed to use the z-buffer for collision detection to generate depth and normal maps. Computation time of their collision detection does not depend on the complexity of the body. The main drawback is that the maps need to be pre-computed before simulation, restricting the real-time application.

Another approach presented by Grzeszczuk et al. [42] uses a neural network to animate dynamic objects. They replaced physics-based models by a large neural network that automatically learns to simulate similar motions by observing the models in action. Their method works in real-time. However, it has not been proven that this method can be used for complex simulation such as cloth.

In [5], Cordier et al have introduced a method for cloth animation in real-time. The algorithm works in a hybrid manner exploiting the merits of both the physical-based and geometric deformations. It makes use of predetermined conditions between the cloth and the body model, avoiding complex collision detection and physical deformations wherever possible. Garments are segmented into pieces that are simulated by various algorithms, depending on how they are laid on the body surface and whether they stick or flow on it.

6. Conclusion

Although the problem of modeling virtual humans have been well-studied area, the growing needs of applications where a variety of realistic, controllable virtual humans call for efficient solutions that automatically generate high-quality models. We have reviewed several techniques, which are devoted to the generation of static and dynamic shape of the human body automatically.

In comparison with undressed body models, little attention has been devoted to the task of dressing automatically virtual human models. This situation will change rapidly, since most of practical applications today involve virtual humans, often crowds, with clothes. This is the case particularly with the growing power of graphics hardware and software techniques for supporting large number of virtual human models in real-time applications.

7. Acknowledgements

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Figure 14. Resizing cloth models in accordance with the body deformation [7].

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