# 3D Web-Based Virtual Try On of Physically Simulated Clothes

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# 3D Web-Based Virtual Try On of Physically Simulated Clothes

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**ABSTRACT**

In this paper we present the Virtual Try On (VTO), an online application that assists users in the evaluation of garments in an online shopping scenario. With the VTO users can create a size-correct virtual representation of themselves, allowing them to virtually try on physically simulated garments which can then be animated. We discuss the requirements of web based physically simulated clothes through a discussion of its building blocks: body sizing, motion retargeting and real-time physically based simulation of resizable and customizable garments. We also discuss its place in a CAD chain from 2D pattern data to the final production of actual garments.

**Keywords:** virtual try on, 3D garment simulation, body resizing, motion retargeting
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## 1 INTRODUCTION

The popularity of online shopping has taken a huge flight over the last decade and fashion retail is no exception. Most major brands have their own web-shops and there are numerous retailers who focus exclusively on online sales. While online shopping is convenient and simple, in the area of fashion retail it cannot replace the actually physical experience of trying on the garments you would like to buy. This often leaves the consumer with doubts about the fit of certain garments and how they would look on their body.

There are currently various web-based systems in use that allow some form of pre-visualization of the clothing for prospective customers, such as [35] and [40]. Most of these systems can be placed in one of two categories based on whether they follow a 2-dimensional or 3-dimensional approach. The 2-dimensional applications provide pre-rendered bodies which can be dressed with garments in a way not unlike paper dolls. Various images are layered on top of each other to provide a dressed virtual model which can be viewed from a set of predetermined viewpoints. The 3-dimensional systems usually dress a virtual model with a static garment mesh whose deformation is only determined by body shape. Both most often provide a certain level of personalization of the body and sometimes even the face.

What most of these systems lack however is a physical basis of the presented results and in most instances there is no underlying CAD pattern data used in the constructions of the 3D garments. Although the available systems allow the customer to evaluate combinations of garments for visual appearance, the evaluation of fit or the assessment of the correct size is still difficult if not impossible. Furthermore a great deal of the appearance of garments lies in their movement and behavior when you walk around. With our VTO, we introduce part of the physical shopping experience into online virtual shopping, through the inclusion of accurate physical simulation of garments with an accurately sized body at the base. Garments can be customized using various sizing and design parameters, while offering immediate, physically correct feedback on the visualization. We also include animation of the user's model, enabling the evaluation of garment behavior while walking around. In the next chapters we discuss the components that make up our VTO as well as their requirements. We furthermore look at the integrated application and will look at possible extensions and improvements.

## 2 THE VIRTUAL TRY ON

The VTO is an application that allows customers to evaluate garments through physical simulation of these garments on an animated virtual avatar sized to their measurements. To achieve this, the VTO integrates 3 separate components: A body sizing module, a motion retargeting module and a garment simulation module. These three modules, which we will describe in the next sections, have been combined in an easy to use module that can be employed in various application scenarios ranging from stand-alone applications to web-plug-ins and server-side applications.

### 2.1 Body Sizing

In order to virtually try on garments, a size-accurate digital representation of the customer is necessary. Nowadays most virtual humans are either hand modeled or obtained using 3D body scanning. But these approaches are time consuming and require expert knowledge. A more user-friendly way of virtual human creation is based on parametric modeling which relies on the deformation of a template body.

Parametric body modeling techniques can be categorized as follows: interactive, reconstructive, example based, anthropometric, and multi layered modeling. To achieve a high degree of realism, a multi-layered approach can be used to generate a body model that allows the interactive design of human bodies [44]. This approach requires intensive user interaction with slow production steps and limited number of control parameters. In case of reconstructive approaches, [32] used silhouette information from orthogonal images to deform a generic body model. Using face and body feature points together with front, back and side images, allows one to construct an animatable human body using Dirichlet Free Form Deformation. Real-time deformations can be achieved by applying Free Form Deformation (FFD) techniques [30] while [53] used a contour based representation of the body model to generate skeleton-driven deformations.

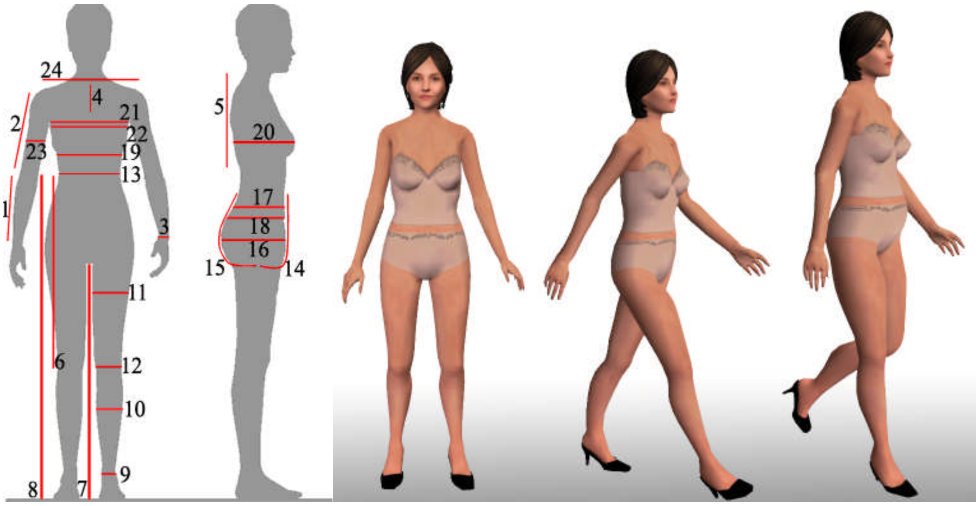



Fig. 1: (a) A template model is created with 24 defined anthropometric regions and corresponding measurements. (b) The animatable model can then be deformed in real-time to any desired morphology.

Recent computer graphics hardware developments allow us to use the GPU for computationally intensive applications. Based on multi-resolution deformation on a high resolution mesh, [36] use the GPU for faster computation of the body deformations. [45] parallelized the computation on GPU to exploit the efficiency of weighted pose space deformation. A recent technique proposed in [49] models muscles using a finite element method in order to reproduce their physical behavior.

An early version of an approach based on examples was presented in [46]. They designed a template human body model with a set of manually defined anthropometric landmarks. According to user specified parameters that correspond to these anthropometric landmarks, a scanned body model database is searched. The model that has the closest similarities to the specified parameters is fetched from the database. As the template model and the fetched one have the same set of predefined landmarks, the template body can be mapped on the other, so it can be deformed to have the same shape. The output of this process is a deformed template model with its adapted skinning information.

One of the other main body modeling techniques is to use anthropometry to segment the body model into logically deformable regions. International body measurement standards are available, defined under ISO-7250 and ISO-8559 (Figure 1, left) which is commonly used in anthropometry studies. These measurements are taken from the main body regions which are sufficient to reconstruct the similar body silhouette. These measurements are mainly used in clothing industry. We employ this technique, as described in [30], within the VTO, Fig. 1. It allows for an intuitive interface in which the users simply enter their body measurements. Using a variation of the FFD technique and radial basis functions, predefined body regions based on anthropometry are deformed to generate the desired body size. Deformation of the model surface is performed in the direction of surface normals. This prevents us from having to recalculate new surface normals, tangent space, and existing skinning weights. The deformations of overlapping body regions are obtained by blending the displacements on the intersecting regions. Continuity between the neighboring regions is preserved by using radial basis functions to produce smooth displacements on the boundaries. Since the anthropometry-based body regions are overlapping with the skeleton joints, the skeleton adaptation is achieved by re-scaling the bones by the same ratio as the region deformed over the joint. This approach makes it possible to dynamically deform the body model while it is being animated.

### 2.2 Motion Retargeting

When deforming the body as described before, the animation assigned to the original body no longer matches the new morphology. Taller people take longer strides and different morphologies result in a different gait. Besides this, potential self penetrations need to be resolved. One of the most successful approaches to modifying an existing animation is to use a space-time optimization. It has been used to address several sub-aspects of the describe problem such as foot plant enforcement, constraint compliance and physical properties of motion. In contrast to the faster Inverse Kinematics (IK), space-time optimization considers the motion clip as a whole [2],[7],[28].

Since recorded motion clips rarely fit the requirements of designers, a significant amount of research has focused on providing tools and methods to reduce the work necessary to create the desired animation. IK has proven to be efficient for self penetrations, but in case of deformable characters, the penetrations created by the growth of a limb tend to last for a long period of time. Using IK for handling these collisions creates discontinuities in the resulting motion and thus the space-time approach seems more appropriate. The first works that used a space-time optimization for adapting a motion were [19] and [20]. Through the definition of a set of constraints the animation is modified to enforce these constraints, while preserving the characteristics of the original motion.

Deforming a character can result in self-intersection of limbs with the body. Ideally we want to resolve these intersections while keeping a plausible animation, i.e. the constraint to satisfy is that the sum of all intersections remains zero. It may be that the penetrations occur at a difficult location, near the arm pit for instance. In this case, only one joint (the shoulder) can be modified to repair the motion, which will cause the entire kinematic chain to be changed. This might lead to visually displeasing results. One might be tempted to move the hand back towards its original location; however this is a bad idea because moving the hand towards the body will create more self penetration. Instead we propose to rotate the forearm towards it initial orientation.

Changes in motion can disturb the balance of the character. This issue can be addressed by modifying the trajectory of the zero momentum point (ZMP) [47],[48] or through energy consumption minimization [1],[43]. Since the considered animation clip might not be optimal in terms of energy consumption, the second criterion is not very useful here. Where previous approaches modified the ZMP trajectory on a per-frame basis, we modify the path of the ZMP using space-time optimization as described by [34]. This allows the character to lean so that the balance is maintained. With badly processed motion data or highly dynamic motion the ZMP does not remain within the supporting area. Instead of bringing it back under the character's foot sole, we bring it back no further than in the original motion clip.

Eventually, footskate may have been created by the adaptation process and should be removed. A five steps kinematics algorithm to remove the foot skating was developed by [31]. We employ a skin-based approach to perform the same cleanup [33] while [18] used a fully IK based approach

## 2.3 High-Speed Garment Animation

While simple computation models are able to simulate in real-time the animation of small fabric samples, simulation of virtual garments on animated virtual characters is a very time-consuming process. They require a lot of computational resources to be dedicated to the mechanical evaluations of each mesh element, along with the numerical integration of the resulting equations. Collision detection furthermore remains an important performance issue, despite the use of sophisticated optimization algorithms.

The still huge performance leap necessary for obtaining real-time simulation of complete garments cannot be achieved by further optimization of classic simulation techniques. They require more drastic simplifications of the simulation process to be carried out, possibly at the expense of mechanical and geometrical accuracy. Among the possibilities are:

- Simulation of features, fold and wrinkles through texturing, bump mapping and smoothing.
- Approximations in the collision interactions between the cloth and the body, for instance using approximate bounding volumes of force fields.
- Highly efficient mechanical models for cloth simulation, based on particle systems associated to efficient numerical integration methods which allow trading away dynamic accuracy to computation speed.
- Approximation of mechanical behavior and motion of cloth into predefined geometric deformations. Problems involve the design of adequate predefined motions that would represent the properties of the cloth in the many different mechanical contexts. These motions are usually defined using analytic functions adapted to a particular context, or by automatic processes such as neural networks "learning" the cloth behavior from actual simulations [10],[21].
- Hybrid context-sensitive simulation frameworks which simplify the computation according to the current interaction context of garment regions, possibly mixing together rough mechanical simulation with small-scale specific simulation of features such as wrinkles [29].
- Integrated body-and-garment simulations where the cloth is defined directly as a processing of the skin, either as texture and bump-mapping (suitable for stretch cloth) or using local deformations reacting to the body motion using simplified mechanics [9].

These techniques can be combined to design a real-time system, provided that the body animation system and the rendering pipeline are efficient enough to support these features with an adequate frame rate.

### *2.3.1 Efficient Mechanical Cloth Simulation*

Among the best suited methods for fast cloth simulation, Particle Systems represent the cloth surface as a set of (connected) masses. Particle Systems have been widely used since the start of cloth simulation in Computer Graphics [5],[14].

The simplest particle systems are spring-mass representations which offer only a representation of the mechanical behavior of the cloth with very limited accuracy. However, their simplicity allows easy use of advanced implicit numerical integration methods [7],[13],[37]. Grid-based structures may enhance the accuracy through the use of Finite-Difference approximations.

The major issue with spring-mass models is their lack of accuracy, particularly when it comes to simulating the nonlinear and anisotropic behavior of cloth materials. Accurate particle-system models can be obtained by accurately formulating strain and stress on the surface of triangle elements according to the positions and forces exerted to its vertices, obtaining a simple implementation of first-order Finite Elements.

A vast set of improvements are available for expressing these models in an optimized and simplified way, allowing the use of efficient integration methods [6],[11],[27]. However, large deformations are required in typical cloth simulations, and therefore totally linear models are not available. While some techniques preserve the tensile linearity of the material using the corotational approach [16],[25],[26],[38],[39],[41], we prefer considering the use of Saint-Venant-Kirchhoff models [3],[4],[12],[23],[42],[54]. This approach allows the simple and explicit expression of the weft, warp and shear material strain out of the triangle element vertex positions, and similarly vertex forces out of the material stress. However, the main interest of the model, described in [52], is to allow the use of arbitrary nonlinear strain-stress curves extracted from tensile test measurements of cloth samples, thus reflecting accurately the true elastic behavior of the cloth material. Such a model can be associated to efficient numerical integration methods usually implemented in particle systems [15],[22],[51]. Among these, the Backward Euler method offers the best compromises between accuracy, computation time and robustness.

### *2.3.2 The Garment Animation System*

High-speed garment animation requires the mechanical model described above to be integrated into an efficient animation system that manages body animation along collision detection with the garment surface. The main idea of this process is to create a unified representation of the body and the garment in a single object, by extrapolating the skinning information from the body surface to the garment surface. This extrapolated information would then be used either for animating the garment geometrically through skinning, or to give to the mechanical simulator in-formation for simplified collision detection between the cloth and the local body surfaces.

The automatic skinning extrapolation tracks the relevant features of the body shape ruling the animation of any vertex of the garment surface. This algorithm can be designed by extending a proximity map (nearest mesh feature algorithm) with additional visibility considerations for pinpointing the actual geometrical dependencies between the surfaces of the body and the cloth. A smooth blend between the weights of several nearest points smoothes the transition between body parts. Additional smoothness criteria can also be also embedded so as to prevent any jaggy deformation over the garment surface. Further optimizations, such as the reduction of bone dependency count, should also be performed for reducing the computational time of skinning animation.

Collision data is obtained from the same nearest-feature algorithm used in the skinning extrapolation scheme, and optimized with specific distance and visibility considerations, Fig. 2. For each vertex of the garment mesh, information relating the nearest body mesh feature is stored. Then, during the animation, this proximity information is incrementally updated with optimized mesh-walking techniques, and active collisions extracted with their relevant geometrical properties (orientation, penetration depth, velocity). Collisions are integrated into the mechanical models as a set of geometrical constraints, complemented with tangential friction forces obtained using a solid friction model. The mechanical engine is a fast and optimized implementation of the tensile cloth model described in the previous section. It is associated to an implicit Backward-Euler integration scheme, which offers good performance along adequate robustness in this simulation context. This allows obtaining a fairly realistic simulation which can suit the needs of fast fitting preview, during body motion, as well as body or garment resizing.

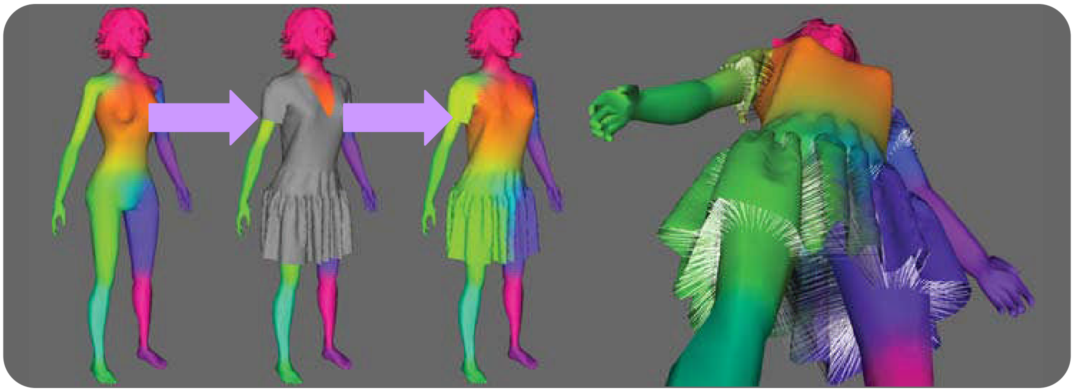
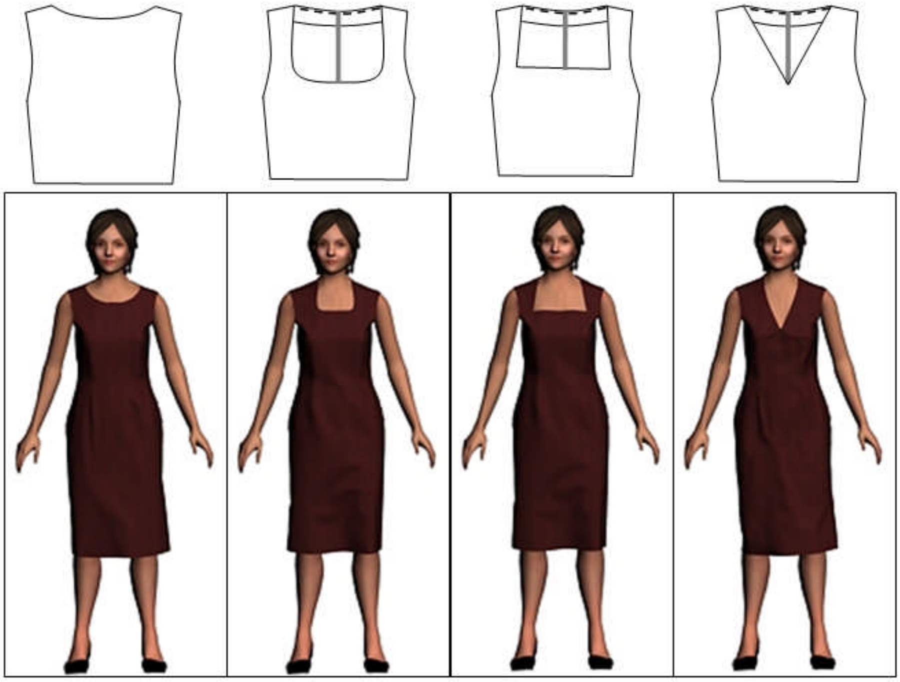


Fig. 2: The skinning weights of the mesh element (shown by the bone colors) are extrapolated on the garment surface. Collision information is stored as vectors relating the orientation and distance of the potentially colliding body surfaces.

### *2.3.3 Garment Customization and Fitting*

Garments can be customized in various ways for matching the intended design. The most obvious change is the customization of appearance and colors, which are achieved through modification of cloth textures and lightning models. Another change is the modification of the geometry of the garment patterns, which can not only be used to change the garment size, but also design features such as local length, stretches, or shapes.

These changes are carried out through inclusion, within the garment surface mesh, of information allowing the proper resizing of the rest state of the mesh depending on garment sizing and customization parameters. As these parameters are modified, the geometry change of the garment mesh is immediately taken into account by the mechanical simulation system, offering immediate preview of the change on the garment drape and animation.



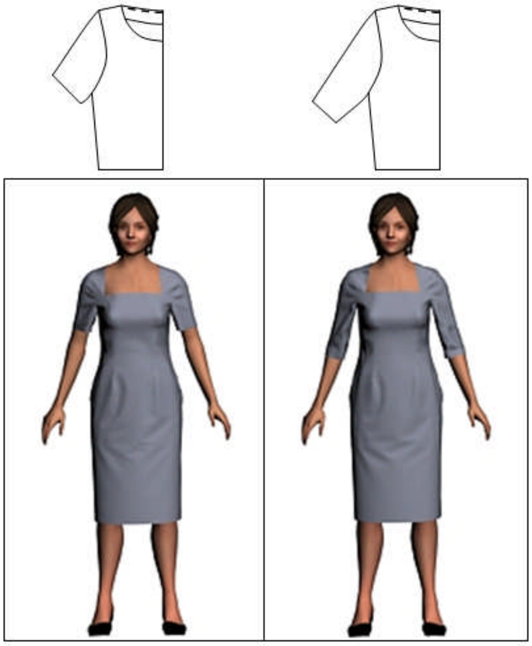


Fig. 3: The pattern based integrated sizing information contained in the garment object allows interactive change of garment design through adjustment of pattern shapes, such as (a) neck lines and (b) sleeve lengths.

Thanks to the accuracy of the mechanical model, the fitting of the garment can also be assessed through adequate visualization techniques that depict the stretch forces within regions of the garment cloth, as well as the pressure exerted by the garment on the body skin, Fig. 4.

Fig. 4: Visualization of the cloth stretch on the garment, which can be affected by the garment design and size, the cloth material, and the body size and posture.

### 2.4 The Virtual Try On Application

The VTO application usually consists of a thin wrapper around what we refer to as the VTO Core. The core is a dynamic library which integrates the three modules we have described. At the time of writing various application scenarios have been developed ranging from a stand-alone application to a web-plug-in and a remote rendering solution. The application provides the user with the appropriate functionality to interact with the virtual model as well as the garments. This interaction can be divided into three stages: Avatar personalization, garment customization and garment evaluation.

To generate a personalized avatar, each user starts out with a template 3D model which can be fully resized using the techniques mentioned before. Although this does allow the user to create his or her size-correct avatar, at that point it still looks like a different person, but with the user's morphology. To allow for further personalization and self-identification we have integrated a retexturing module which, based on a photo of the user, recognizes the user's face and applies this to the 3D model, as well as adapts the avatar's skin color to that of the user, as demonstrated in Fig. 5. Although not necessarily a requirement for accurate simulation, we find that this enhances the user experience and identification with the final result.

Fig. 5: Starting from a template avatar and based on a user's photo, avatars are personalized through a face detection based retexturing of the body.

Once a personalized avatar is generated, it can be dressed with any available 3D garment. Depending on the available options a garment can be customized to the user's liking. Customizations range from switching between standard dress sizes and design features as discussed earlier, as well as the selection of available fabric types and colors. All of these customizations can be performed in real-time and without the need to load new models. Fig. 6 demonstrates the different results that can be obtained through avatar personalization and garment customization, demonstrating both the power and flexibility of our system. Notice the difference in body morphology of the three avatars as well as the differences achieved through customization of the garments.

Within the VTO the real-time simulation is always active once a garment is loaded. Once full customization has been completed however, there is an optional third stage involving higher quality simulation. In this stage the user can choose to record a movie of the animated avatar. At this stage a second simulation mode is selected which performs a higher quality dynamic simulation of the garment resulting in more realistic simulations. Although this mode sacrifices some of the speed for increased accuracy, the average recording time for an animation of 15-20 seconds never exceeds several minutes.

Fig. 6: Screen captures from 3 customized bodies and garments in the real-time VTO, all starting from the same template.

## 3 CONCLUSION

In this paper we have discussed our work on the Virtual Try On and its essential building blocks. The Virtual Try On as presented in this paper improves upon existing VTO solutions by providing both animation of the avatar and realistic physical simulation of the 3D garments. The combination of these qualities provides the user with an application that can provide more insight into garment behavior and fit in an online shopping scenario.

Not only do we think that the VTO serves a purpose as an application in its own right, we also consider it a valuable and maybe even necessary element in a complete CAD tool chain from design to production. For example, since within the application we always maintain a direct connection to the underlying CAD data, we envision exporting the results of our interactive 3D configuration to 2D CAD data that can be fed into fabric cutters, pattern plotters or maybe even sewing robots to produce the 3D customized and personalized garments.

As can be expected for these types of applications, the bottlenecks are in the garment simulation and collision detection. However, as stated before, it is not possible to obtain huge increases in performance through further optimization of classic simulation techniques. In recent years however, other possibilities have presented themselves in terms of hardware developments such as multi-core CPUs and GPUs. We learn from these developments that optimization through parallelization is a viable route to take. We envisage that this might not only lead to faster client-side (web-)applications but could also pave the way for remote computation solutions, allowing even simple client-side hardware to run the VTO over a network. This would open up the presented platform to mobile devices such as netbooks and mobile phones through thin web applications.

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# REFERENCES

[1] Abe, Y.; Liu, K.; Popovic, Z.: Momentum-based parameterization of dynamic character motion, Graphical Models (Special Issue on SCA 2004), 68(2), 2004, 194-211.

[2] Baerlocher, P.; Boulic, R.: An Inverse Kinematic Architecture Enforcing an Arbitrary Number of Strict Priority Levels, The Visual Computer, 20(6), 2003, 402-417.

[3] Barbic, J.; James, D.L.: 2005, Real-Time Subspace Integration for St.Venant-Kirchhoff Deformable Models, ACM Transactions on Graphics (ACM SIGGRAPH 2005 proceedings), 24(3), 2005, 982-990.

[4] Bonet, J.; Wood, R.: Nonlinear Continuum Mechanics for Finite Element Analysis, Cambridge University Press, Cambridge, 1997.

[5] Breen, D.E.; House, D.H.; Wozny, M.J.: Predicting the Drape of Woven Cloth using Interacting Particles, SIGGRAPH '94: Proceedings of the 21st annual conference on Computer graphics and interactive techniques, 1994, 365-372.

[6] Bro-Nielsen, M.; Cotin, S.: Real-Time Volumetric Deformable Models for Surgery Simulation using Finite Elements and Condensation, Eurographics 1996 proceedings, 1996, 21-30.

[7] Choi, K.J.; Ko, H.S.: Online Motion Retargeting, Journal of Visualization and Computer Animation, 11(5), 2000, 223-235. doi:10.1002/1099-1778(200012)11:5<223::AID-VIS236>3.0.CO;2-5

[8] Choi, K.J.; Ko, H.S.: Stable but Responsive Cloth, Computer Graphics (SIGGRAPH'02 proceedings), 21(3), 2002, 604-611.

[9] Cordier, F.; Magnenat-Thalmann, N.: Real-Time Animation of Dressed Virtual Humans, Computer Graphics Forum, 21(3), 2002, 327-336. doi:10.1111/1467-8659.t01-1-00592

[10] Cordier, F.; Magnenat-Thalmann, N.: 2005, A Data-Driven Approach for Real-Time Clothes Simulation, Computer Graphics Forum, 24(2), 2005, 173-183.

[11] Cotin, S; Delingette, H.; Ayache, N.: Real-Time Elastic Deformations of Soft Tissues for Surgery Simulation, IEEE Transactions on Visualization and Computer Graphics, 5(1), 1999, 62-73.

[12] Debunne, G.; Desbrun, M.; Cani, M.P.; Barr, A.H.: Dynamic Real-Time Deformations Using Space & Time Adaptive Sampling, SIGGRAPH '01: Proceedings of the 28th annual conference on Computer graphics and interactive techniques, 2001, 31-36.

[13] Desbrun, M.; Schröder, P.; Barr, A.H.: Interactive Animation of Structured Deformable Objects, Proceedings of the 1999 conference on Graphics Interface, Morgan Kaufmann Publishers, 1999, 1-8.

[14] Eberhardt, B.; Weber, A.; Strasser, W.: A Fast, Flexible, Particle-System Model for Cloth Draping, Computer Graphics in Textiles and Apparel (IEEE Computer Graphics and Applications), IEEE Press, 1996, 52-59.

[15] Eberhardt, B.; Etzmuss, O.; Hauth, M.: Implicit-Explicit Schemes for Fast Animation with Particles Systems, Proceedings of the Eurographics workshop on Computer Animation and Simulation, Springer-Verlag, 2000, 137-151.

[16] Etzmuss, O.; Gross, J.; Strasser, W.: Deriving a Particle System from Continuum Mechanics for the Animation of Deformable Objects, IEEE Transactions on Visualization and Computer Graphics, IEEE Press, 2003, 538-550.

[17] Etzmuss, O.; Keckeisen, M.; Strasser, W.: A Fast Finite Element Solution for Cloth Modeling, Proceedings of the 11th Pacific Conference on Computer Graphics and Applications, IEEE Computer Society, 2003, 244-251.

[18] Glardon, P.; Boulic, R.; Thalmann, D.: Robust on-line adaptive footplant detection and enforcement for locomotion, The Visual Computer, 22(3), 2006, 194-209.

[19] Gleicher, M.: Retargetting motion to new characters, Proceedings of SIGGRAPH 1998, ACM Press, New York, 1998, 33-42. doi:10.1145/280814.280820

[20] Gleicher, M.: Litwinowicz, P.: Constraint-based motion adaptation, The Journal of Visualization and Computer Animation, 9(2), 1998, 65-94.

[21] Grzezczuk, R.; Terzopoulos, D.; Hinton, G.: Neuroanimator: Fast Neural Network Emulation and Control of Physics-Based Models, Proceedings of the 25th annual conference on Computer graphics and interactive techniques, ACM, 1998, 9-20.
[22] Hauth, M.; Etzmuss, O.: A High Performance Solver for the Animation of Deformable Objects using Advanced Numerical Methods, Computer Graphics Forum (Eurographics 2001 proceedings), 2001, 319-328.
[23] Hauth, M.; Gross, J.; Strasser, W.: Interactive Physically-Based Solid Dynamics, Proceedings of the 2003 ACM SIGGRAPH/Eurographics Symposium on Computer Animation, 2003, 17-27.
[24] Hauth, M.; Etzmuß, O.; Straßer, W.: Analysis of Numerical Methods for the Simulation of Deformable Models, The Visual Computer, 19(7–8), 2003, 581–600.
[25] Hauth, M.; Strasser, W.: Corotational Simulation of Deformable Solids, WSCG 2004 proceedings, 2004, 137-145.
[26] Irving, G.; Teran, J.; Fedkiw, R.: Invertible Finite Elements for Robust Simulation of Large Deformation, Eurographics Symposium on Computer Animation, 2004, 131-140.
[27] James, D.; Pai, D.: ArtDefo - Accurate Real-Time Deformable Objects, Computer Graphics (SIGGRAPH'99 proceedings), ACM Press, 1999, 65-72.
[28] Jeong, K.; Lee, S.: Motion Adaptation with Self-intersection Avoidance, Proceedings of the International Workshop on Human Modeling and Animation, 2000, 77-85.
[29] Kang, Y.M.; Choi, J.H.; Cho, H.G.; Lee, D.H.; Park, C.J.: Real-Time Animation Technique for Flexible and Thin Objects, WSCG'2000 proceedings, 2000, 322-329.
[30] Kasap, M.; Magnenat-Thalmann, N.: Parameterized Human Body Model for Real-time Applications, CW '07. International Conference on Cyberworlds, 2007, 160–167.
[31] Kovar, L.; Schreiner, J.; Gleicher, M.: Footskate cleanup for motion capture editing, Proceedings of the 2002 ACM SIGGRAPH/Eurographics symposium on computer animation, ACM Press, 2002, 97-104.
[32] Lee, W.-S.; Gu, J.; Magnenat-Thalmann, N.: Generating animatable 3D virtual humans from photographs, Computer Graphics Forum (Eurographics 2000), 19(3), 2000, 1-10.
[33] Lyard, E.; Magnenat-Thalmann, N.: A simple footskate removal method for virtual reality applications, The Visual Computer, 23(9), 2007, 689-695. doi:10.1007/s00371-007-0135-6
[34] Lyard, E.; Magnenat-Thalmann, N.: Motion adaptation based on character shape, Computer Animation and Virtual Worlds, 19(3-4), 2008, 189-198. doi:10.1002/cav.233
[35] Mannequin Virtuel, http://www.vb2s.com/?p=50, VB2S.
[36] Marinov, M.; Botsch, M.; Kobbelt, L.: Gpu-based multiresolution deformation using approximate normal field reconstruction, Journal of graphics tools, 12(1), 2007, 27–46.
[37] Meyer, M.; Debunne, G.; Desbrun, M.; Barr, A.H.: Interactive Animation of Cloth-like Objects in Virtual Reality, Journal of Visualization and Computer Animation, 12(1), 2001, 1-12.
[38] Muller, M.; Dorsey, J.; McMillan, L.; Jagnow, R.; Cutler, B.: Stable Real-Time Deformations, Proceedings of the Eurographics Symposium on Computer Animation, 2002, 49-54.
[39] Muller, M.; Gross, M.: Interactive Virtual Materials, Proceedings of Graphics Interface, Canadian Human-Computer Communications Society, 2004, 239-246.
[40] My Virtual Model, http://www.mvm.com, My Virtual Model Inc.
[41] Nesme, M.; Payan, Y.; Faure, F.: Efficient, Physically Plausible Finite Elements, Eurographics 2005 proceedings (short papers), 2005, 77–80.
[42] O'Brien, J.; Hodgins, J.: Graphical Modeling and Animation of Brittle Fracture, Computer Graphics (SIGGRAPH'99 proceedings), ACM Press, 1999, 137-146.
[43] Popovic, Z.; Witkin, A.: Physically based motion transformation, Proceedings of SIGGRAPH 1999, ACM Press, New York, 1999, 11-20. doi:10.1145/311535.311536
[44] Porcher Nedel, L.; Thalmann, D.: Modeling and deformation of the human body using an anatomically-based approach, Proc. Computer Animation '98, IEEE Computer Society Press, 1998, 34–40.
[45] Rhee, T.; Lewis, J.P.; Neumann, U.: Real-time weighted pose-space deformation on the GPU, Computer Graphics Forum, 25(3), 2006, 439–448. doi:10.1111/j.1467-8659.2006.00963.x
[46] Seo, H.; Magnenat-Thalmann, N.: An example-based approach to human body manipulation. Graph. Models, 66(1), 2004, 1–23. doi:10.1016/j.gmod.2003.07.004

[47] Shin, H.J.; Kovar, L.; Gleicher, M.: Physical touch-up of human motions, Proceedings of the Pacific conference on computer graphics and applications, IEEE Computer Society, Wiley-IEEE Computer Society Press, 2003, 194.
[48] Tak, S.; Ko, H.-S.: A Physically-based Motion Retargeting Filter, ACM Transactions on Graphics, 24(1), 2005, 98-117. doi:10.1145/1037957.1037963
[49] Teran, J.; Sifakis, E.; Blemker, S.; Ng-Thow-Hing, V.; Lau, C.; Fedkiw, R.: Creating and simulating skeletal muscle from the visible human data set, IEEE Transactions on Visualization and Computer Graphics, 11(3), 2005, 317–328. doi:10.1109/TVCG.2005.42
[50] Volino, P.; Magnenat-Thalmann, N.: Accurate Garment Prototyping and Simulation, Computer-Aided Design & Applications, 2(5), 2005, 645-654.
[51] Volino, P.; Magnenat-Thalmann, N.: Implicit Midpoint Integration and Adaptive Damping for Efficient Cloth Simulation, Computer Animation and Virtual Worlds, 16(3-4), 2005, 163-175.
[52] Volino, P.; Magnenat-Thalmann, N.; Faure, F.: A Simple Approach to Nonlinear Tensile Stiffness for Accurate Cloth Simulation, ACM Transactions of Graphics, 28(4), 2009, 105-116.
[53] Wang, Z.; Mao, T.; Xia, S.: A fast and handy method for skeleton driven body deformation, Computers in Entertainment, 4(4), 2006, article 6.
[54] Zhuang, Y.; Canny, J.: Haptic Interaction with Global Deformations, Proceedings of the IEEE International Conference on Robotics and Automation, IEEE Press, 2000.