Fitting Close-to-Body Garments with 3D Soft Body Avatars

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Abstract

We describe the first end-to-end system, called VitalFit, for predicting the fit of close-to-body garments using soft body avatars. Soft body avatars may be constructed by registering our VitalBody template to existing rigid avatars, or directly to 3D body scans. The resulting soft avatar includes a tetrahedral mesh and soft tissue material properties that may be numerically simulated using the finite element method (FEM). Designers, fit specialists, and pattern engineers may create virtual garments and evaluate fit using VitalFit DX, a plugin for Adobe Illustrator®. Users can import existing patterns or create them anew, and modify the patterns using the familiar tools in Adobe Illustrator®. In VitalFit the garment and body are simulated together, with two-way coupling of forces and displacements. This allows us to predict how human soft tissues deform in contact with the garment. We can also predict stresses and strains in both garment and body. VitalFit can simulate the coupled dynamics of soft tissues and garment, during running and other activities of daily living. These new tools can be used to predict not only static fit, but also how a garment may function in real life.

Keywords: avatar, apparel, soft-body, deformable, simulation, fit, dynamics, garment, clothing, virtual prototyping

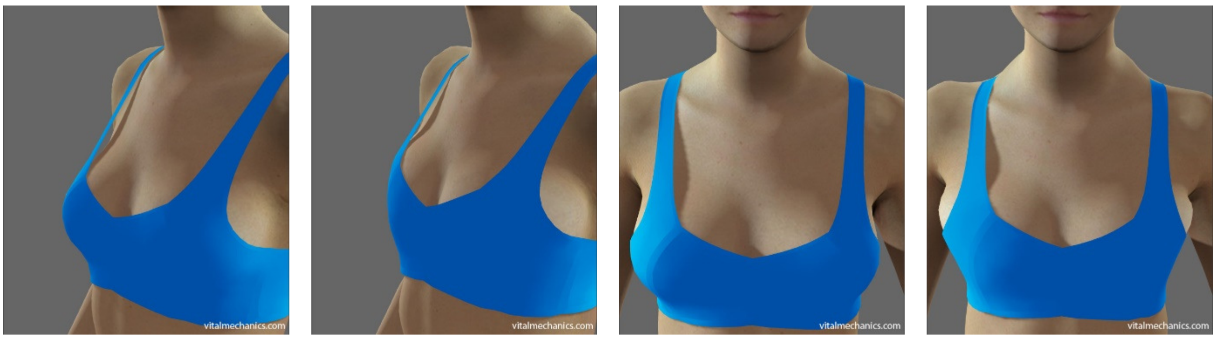


Fig. 1. Comparison of fit using a traditional rigid avatar and VitalFit's soft avatar.

1. Introduction

A long standing goal for 3D digital human models ("avatars") has been to use such models to predict the fit and function of garments. Many software solutions have been developed for simulating garment drape on human body avatars (e.g., [1, 2, 3, 4, 5, 6]). While previous solutions simulate the physics of the garment, the human avatar itself has been modeled as a rigid 3D shape. Recent developments have increased the accuracy and detail of body shape representations using 3D scanning technologies, and are able to animate movements such as running. These developments can produce realistic simulation of drape and are well suited for loose-fitting garments. However, the avatars are kinematically animated and remain essentially rigid, like an articulated mannequin – the garment does not affect the human body shape or movement. This is a serious limitation of previous work. The human body is obviously soft and its shape and motion are significantly affected by contact with clothing.

Indeed, the *raison d'être* of many garments, such as the bra, is to shape the body (e.g., to create a desired profile) and its motion (e.g., to provide support). This is a critical issue for all close-to-body garments, including intimates, sports bras, leggings, tight-fitting jeans, compression stockings, and even wearable devices and footwear. Figure 1 shows that fit simulation using a rigid avatar can fail to predict the shape of the breast when wearing a tight sports bra; our VitalFit soft body avatar produces more realistic results.

Here we introduce a complete system, called VitalFit, for constructing soft avatars (Figure 2) and simulating their two-way interaction with garments using finite element methods (see Section 2). In Section 3 we describe VitalFit DX, a plugin for Adobe Illustrator® for interacting with the simulations, and modifying garment patterns to improve fit (see Figure 5). We conclude in Section 4 with a summary of the contributions and a preview of work to be completed in the near future.

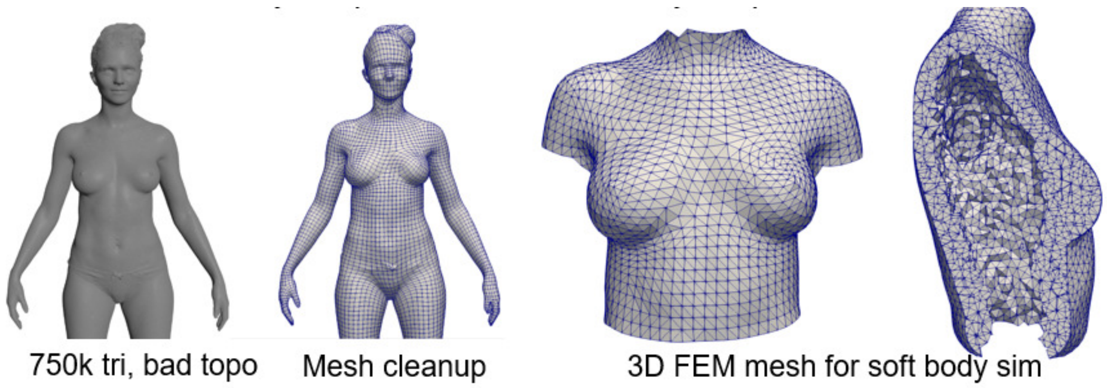


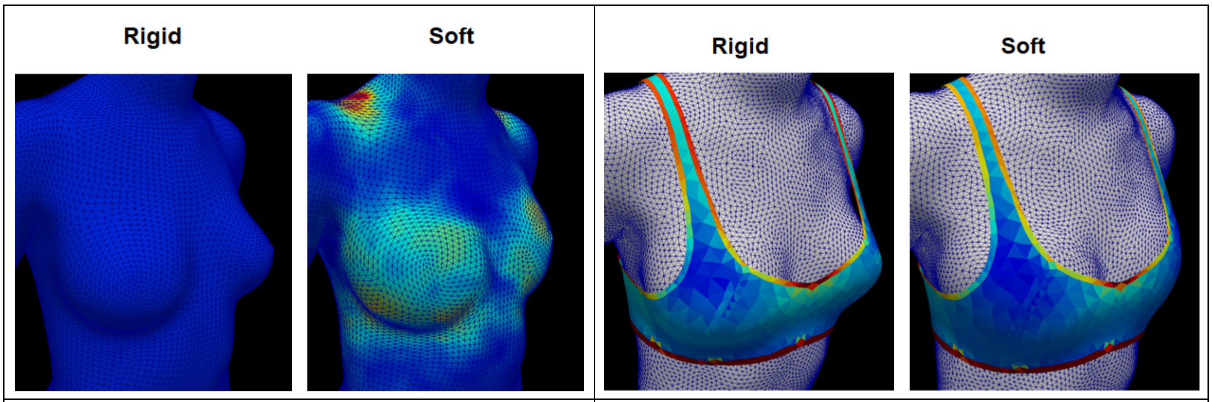
Fig. 2. Personalization of our VitalBody using a 3D scan.

2. Simulating Soft Body Avatars with VitalFit

We can construct soft body avatars from most representations of body shape in a reference pose. The input to our system may be either the surface mesh of an existing 3D avatar or a 3D body scan. Utilizing body scans enables personalization of the soft avatar to the body of an individual guest or fit model (see Figure 2). However, 3D scans, even when made water tight, often suffer from poor surface mesh topology, and are not directly suited for finite element simulation. Therefore, we developed VitalBody, a 3D template of the human body which includes a tetrahedral mesh carefully designed for simulation using the finite element method. The VitalBody template is registered to the body geometry to create a personalized soft avatar.

The template also includes a rig that can be used to animate the body performing a wide range of movements. Unlike traditional rigid avatars that dictate how the surface of the body moves, we animate an inner body layer and our soft avatar's volumetric skin layer (described below) deforms in response to the garment (see Figures 3 and 4).

VitalFit simulates how the garment behaves in close contact with the deformable body using the finite element method. The garment and body are simulated together, with two-way coupling of forces and displacements. This allows us to predict how human soft tissues deform in contact with the garment, as well as the stresses and strains in both the garment and the body (see Figure 3). Such information may be used to understand the garment's fit and feel, and perhaps how it may fail.



(a) Body Strain | (b) Garment Stress

Fig. 3. Finite element simulation of a soft avatar provides quantitative information that is relevant to fit. (a) The surface strain on the body is relevant to the feeling of comfort. A rigid avatar (left) provides no information about tissue strain, while our soft avatar (right) can reveal hotspots of high strain. (b) The stresses in the garment are affected by soft body deformation. When using a rigid avatar (left), the estimates of garment stress may be less accurate since they do not account for the change in body shape due to deformation; such body deformations are captured by a soft avatar (right).

The tissues of the human body are anisotropic and highly non-linear in compression. The thickness of the tissue layer has a great influence on how the body behaves due to contact. The skin and underlying soft tissues are relatively thin in many regions, with significant sliding behavior.

To create a realistic soft body avatar with these properties we developed a novel "Sliding Thick Skin" (STS) tissue model [10]. The STS model represents the soft tissue covering the body of the avatar as a volumetric skin layer that can slide over the inner body surface. The volumetric part is modeled as a non-linear hyperelastic material (a generalized Rivlin-type polynomial model) [12, 8]. The inner surface of the thick skin is elastically coupled to the inner body surface upon which it slides, approximating both the effect of connective tissue fascia and neighbouring soft tissues.

We briefly sketch the simulation method here. The soft tissue layer is discretized into a 3D mesh. The state of the body mesh is denoted x_b. This state includes the coordinates of the position of the point associated with each mesh vertex, and may include the velocity of the point for simulating dynamics. The garment is also discretized into a mesh, with vertex state x_c. We simulate static fit and dynamics using a variational formulation of the finite element method. We simultaneously optimize the physical state of both the garment and the body, subject to these contact constraints. Mathematically, we optimize the total "energy" of the combined system $W_c(x_b)+W_b(x_b)$, subject to contact constraints, where W_c is an energy-like objective function of the garment and W_b is a similar energy of the body. These energies include the elastic potential energy, and may include other quantities (e.g., Gibbs' potential) needed for simulating dynamics. A major challenge addressed in our software is robust treatment of non-penetration constraints between the garment and body, and sliding constraints between the soft tissue layer and the inner body.

The inner body may be animated using the rig associated with VitalBody. We can simulate the dynamics of both soft tissues and garment during running and other activities of daily living. Figure 4 shows a few frames of a running simulation (the motions are much easier to see in the video). The simulation captures the effect of body movement and contact with the ground, on both the body and the garment. Thus we can predict not only static fit, but also how a garment may function in real life.

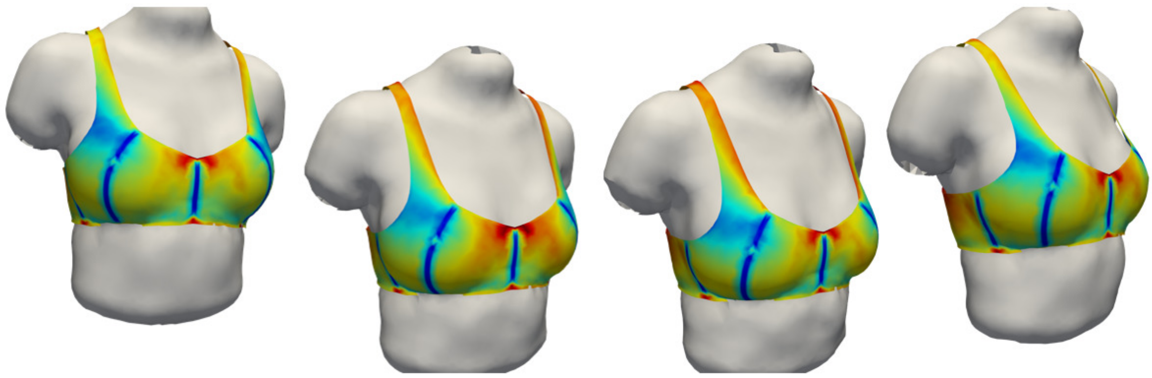


Fig. 4. Dynamic simulation of running with VitalFit. A part of the gait cycle is shown, around the time of ground contact. Observe the changes in both breast shape and garment strain.

3. VitalFit DX: Designing Garments to Fit Soft Bodies

We have developed VitalFit DX, a software solution that makes it easy to design garment patterns, stitch them together, assign material properties to different parts of the garment, and visualize fit (see Figure 5). It is particularly well suited for constructing virtual close-to-body garments and evaluating fit with soft avatars. VitalFit DX is delivered as a plugin for Adobe Illustrator®, a widely used application familiar to the apparel design community. A major advantage of VitalFit DX is that designers and pattern makers can use the sophisticated, fully featured, extensible, and familiar tools in Adobe Illustrator®, instead of learning a new proprietary interface.

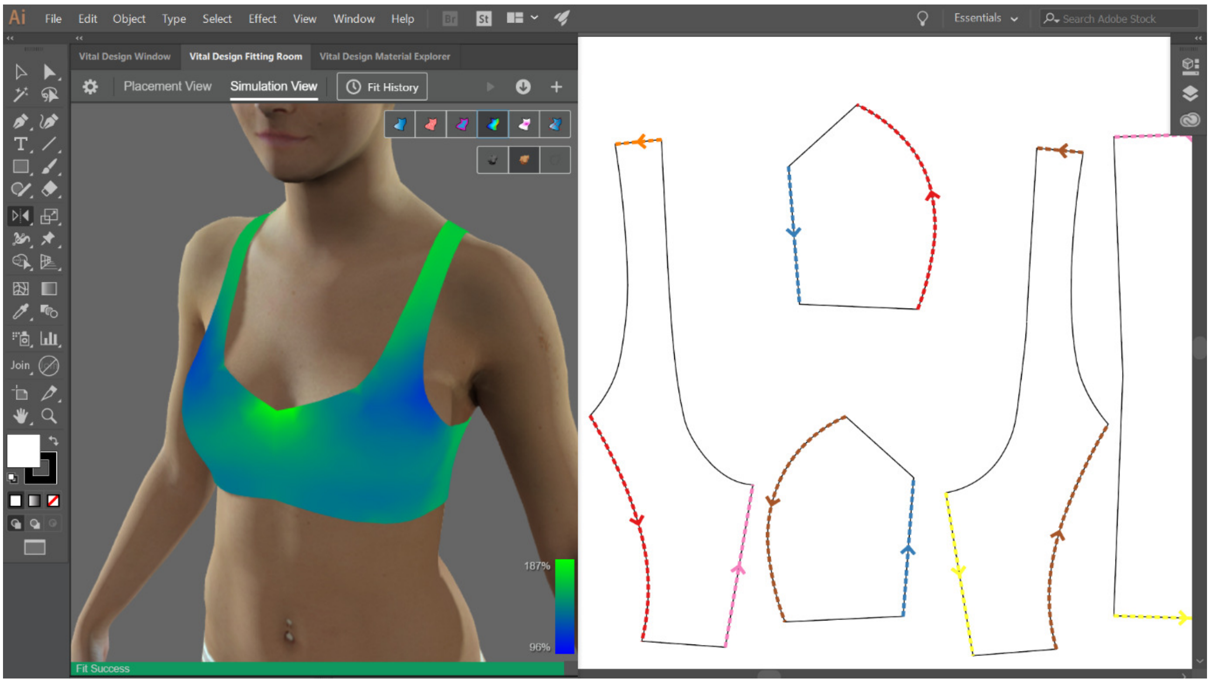


Fig. 5. VitalFit DX plugin for Adobe Illustrator®. Pattern pieces on the artboard (right) are shown stitched with our custom Join tool. The 3D Fitting Room on the left shows the garment fitted on to an avatar. Simulation data, such as strains, may be visualized.

VitalFit DX can read and write patterns using open standards (e.g., DXF-ASTM) and therefore could interoperate with third party software. New garments may also be constructed from scratch, starting from vector graphics artwork in Adobe Illustrator®. For example, a block pattern could be designed and optimized for fit using VitalFit DX and then exported for detailed design and marker making with third party software. Another possible workflow is to use VitalFit DX to evaluate the fit of a previously designed garment pattern.

Pattern pieces may be stitched together using custom tools we have added to the tools panel in Adobe Illustrator®. Using the Join tool, paths on pattern pieces to be joined may be selected in the artboard and stitched together. In Figure 5, the stitched edges of the pattern pieces are shown on the artboard on the right with colored arrows. Pieces may be placed on the body using VitalFit DX's "body map," an unwrapped 2D representation of the body. Material properties may be assigned to different pattern pieces and regions.

Once the virtual garment has been assembled and placed approximately on the avatar, we can simulate the fit of the garment using VitalFit. Simulation results may be viewed in the 3D Fitting Room panel within Adobe Illustrator®. The Fitting Room allows the garment and body to be viewed from different angles. The garment may be visualized either using photorealistic textures and lighting, or using color maps to show stress, strain, materials, and other data. Simulation data may be saved in the fit history for comparing and evaluating different design choices.

One of the most powerful aspects of VitalFit DX is integration with Adobe Illustrator®. Garment patterns may be viewed and modified using the mature and sophisticated tools built into Adobe Illustrator®. For example, the shape of a pattern piece can changed and the fit recomputed using a few mouse clicks, all within the same environment. All data related to garment fit are stored within the `.ai` file, simplifying integration with PLM software.

4. Conclusions and Future Work

Taken together, these new tools enable a digital transformation of the traditional garment pipeline for close-to-body garments. Such garments have been challenging to design using traditional rigid 3D avatars. Virtual prototypes may be quickly and inexpensively constructed and tested with our soft avatars, reducing the time and cost of garment development and merchandizing. VitalFit may also be used for virtual try-on and online garment selection, and to personalize garments to 3D scans specific individuals.

VitalFit is new technology that is being actively developed and continues to evolve based on the needs of users. One important aspect is that, in addition to sophisticated simulation algorithms, realistic fit prediction requires accurate material properties of both garments and the human body. While technology for fabric property measurement is mature and widely available, standardized measurement protocols have been designed for fabric quality assurance and not garment simulation. There is currently no standard for exchanging the full range of fabric material data required for simulation. We hope to work with the IEEE 3D Body Processing group to develop industry standards for exchange of such data.

Soft body avatars are very new, and to our knowledge, VitalFit is the first system to use soft avatars for fit prediction. Remarkably, the material properties required for contact simulation and the distribution of these properties over the human body had never been measured before. These properties can not be reliably reconstructed from optical or imaging data (e.g., [13, 11, 7]) and require actual contact with the soft object being measured [9]. We have recently shown how soft tissue properties of individual human participants may be measured, in vivo, using a novel probe developed in our laboratory [10]. We are currently building a unique database of human body material properties that will be used to create the next generation of highly realistic data-driven soft body avatars..

Acknowledgements

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