Leveraging Low Cost Body Models for Personal Care Product Evaluation

Chris Pieper

Kimberly-Clark Corporation

***Abstract**:* Simulating the human body is complex, and detailed models have been used to describe aspects of its physiology. Examples of applications include simulated crash tests, joint replacements and even a modelling of a beating heart. When evaluating a product interacting with the body, the body may not be the primary analysis objective, but rather is a necessary participant in the simulation. Disposable personal care products, such as absorbent incontinence garments or feminine care offerings, often interact intimately with the body and are intended to fit a range of body sizes and shapes. Virtual evaluations of these products often consider many body sizes and shapes; however, the cost of complex human models for product evaluation can limit the number of use cases considered. Here, cost refers to the price and resource expense of obtaining geometry, creating a finite element definition and the computation of the model. This paper describes techniques used to provide low cost virtual articulated humans suitable for product evaluation.

The advent of faster, simpler yet sufficiently accurate body models allows evaluation of virtual products over more realistic human user populations. This allows personal care product models to put more focus on performance of the product, which is the true goal of virtual product evaluation. By contrast previous capabilities requiring significant computational and body model building resources, resulted in limited testing over a small user population. Faster and simpler models permit more virtual product tests in a given time allowing consideration of both common and less common body shapes/sizes. Consideration of more product users provides greater confidence in the product's design as it progresses through the development cycle.

The examples featured leverage high quality digital bodies generated by a body model commercialized by Body Labs, Inc. Using a statistical model (SMPL) to provide high quality virtual human shapes in multiple poses eliminates the effort and challenges associated with converting scan data into a usable finite element model. Further, the simplified approach of defining an articulated skeleton, or other internal features/properties, in Abaqus as node sets rather than as discrete regions provides a means to represent complex internal composition in a computationally efficient manner while maintaining the essence of internal complexity. Another application uses poseable body model output to define a global model and eliminates the need to represent much of the internal body detail altogether. Several examples highlighting the benefits of these techniques are provided to further illustrate the concepts and their advantages.

***Keywords**: Body Model, Virtual Prototype, Statistical Body Model, SMPL, Virtual Product Testing, Nodal Material Specification.*

1. Introduction

Finite element analysis is used to evaluate the performance of personal care products interacting with a virtual human user (US Patent No. 6810300, 2004) (US Patent No. 7099734, 2006) (US Patent No. 7373284, 2008). Some products intimately interact with the body such that together, they define a system for analysis. While the detailed structure and function of a human is quite complex, the human is not the focus of the product evaluation, therefore the body is simplified to make simulation feasible. Simulation detail emphasis is placed on the product being evaluated since this is the goal of the analysis. Although the body is not the focus of the analysis, it still must be reasonably represented in the simulation. Therefore, the problem at hand becomes how to represent a human body with sufficient accuracy to allow a realistic product evaluation.

Over the past several years, we have used several strategies to represent the human body for product evaluations. Simulation strategies involved various levels of complexity, robustness and perceived accuracy (appearance of realism). Even in our most detailed representations, the body was treated as a passive structure while in reality, the body is active, using its muscles to initiate and control movement. Activation of muscles affect local soft tissue properties and the resulting body shape (both due to change of pose and change in tissue/muscle shape). This article will review one of our previous body modeling strategies and contrast it with newly developed approaches. Focus is placed on the lower torso as this is of primary interest for personal care absorbent products, but the techniques apply to other regions of the body as well.

2. Modeling Approaches

2.1 Legacy Body Modeling Process

2.1.1 Geometry Definition

The legacy method of defining human lower torso model geometry involved obtaining body scan data, from laser, photogrammetric or other scanning technologies, in the form of a point cloud. The point cloud data was subsequently converted to a geometric surface (e.g., NURBS surface) using surfacing software and imported into Abaqus/CAE. The surfacing step, consisting of using point cloud data to define a NURBS surface, is both time consuming and often results in a surface of reduced fidelity compared to the original subject or the point cloud. In CAE, the closed surface is converted to a solid, deformable body.

Acquisition of the point cloud data can take weeks to months if not already available from a scan library. Therefore, if interested in a particular user size/shape, a target user must be identified and pulled from an existing library or recruited, scanned and surfaced with the latter option taking weeks to months to complete. The available population of virtual users is therefore limited to people who have already been scanned and exist in a library or people that can be found, recruited and are willing and able to be scanned.

2.1.2 Skeletal Framework

Using a collection of supplemental point coordinates specific to each torso geometry, a series of geometric planes are defined and used to partition the solid torso in such a way that internal edges are created. Some of these internal edges, formed by the intersection of cutting planes, are used to define rigid body constraints and represent a simple skeletal structure as illustrated in figures 1 and 2.

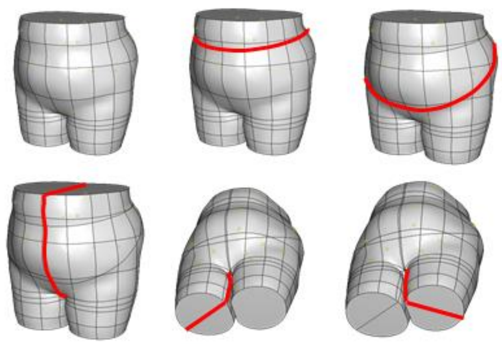

Figure 1. Planar partitions used to generate internal skeletal structure. Planes are defined based on coordinates of key points associated with the torso geometry.

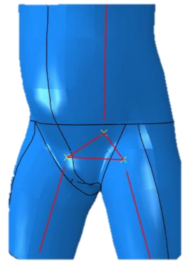

Figure 2. Resulting skeletal structure defined using internal edges (intersections of partitioning planes). The highlighted edges are used to define rigid body constraints to represent bones.

Finally, with the bone structure defined, simple rules are used to define a temperature field within the torso where the local temperature depends on nodal proximity to either the skin surface or internal bones. The temperature field is used in conjunction with a temperature dependent material definition which provides a crude stiffness gradient inside the body finite element model.

2.1.3 Motion Specification

Articulation of the simple bone structure is facilitated using (basic translational join) connectors, representing ball and socket joints, to connect adjacent bones. The pose of the torso is controlled by specifying rotations of reference points associated with these joint connectors. The torso structure deforms as result of driving the joints and consequently, the associated rigid bones and connected elements. This movement is passive in that the shape of the torso changes due to the displacement of the internal bone mechanism and not due to simulated muscle activation.

2.1.4 Method Assessment

This strategy has provided an effective method to define and control a lower torso for virtual product evaluations. However, the model definition process relies on the availability of body scan geometry which is otherwise timely to acquire. An additional complication potentially arises from the partitioning process which can create very small or oddly shaped internal regions. Additional internal edges, beyond those associated with the desired bone layout, put unnecessary constraints on the mesher and can result in a mesh that includes non-physical internal detail where none is needed or wanted.

2.2 Body Shape Model with Internal Node Sets

2.2.1 Geometry Definition

Rather than being constrained by available body scans, a statistical body topology model is used in an improved body modeling process. A Skinned Multi-Person Linear Model (SMPL) (Loper M. , Mahmood, Romero, Pons-Moll, & Black, 2015), developed at Max Planck Institute for Intelligent Systems, is described on the Body Labs, Inc. website (Body Labs, 2016) as "a learned model of human body shape and pose-dependent shape variation that is more accurate than previous models and is compatible with existing graphics pipelines." The model, commercialized by Body Labs, provides a high quality surface mesh and corresponding joint centers. A custom algorithm is used to extract the lower torso from the body model and close the resulting holes. The lower torso surface mesh is imported into Abaqus/CAE as an orphan mesh and converted to a volume (tetrahedral) mesh using mesh editing tools.

2.2.2 Skeletal Framework

The skeletal definition strategy was enhanced by using the SMPL model's prediction of joint centers to scale and orient anatomical bones inside the body's surface as shown in figure 3. A geometric search algorithm is used to identify interior nodes within the lower torso volume mesh that lie inside each of the bones. Sets are defined for the nodes associated with each bone volume and are subsequently used to define rigid body constraints using a reference point located at the bone's joint center. As with the previous strategy, joints are represented by connectors and motions are specified by rotations of bone reference nodes.

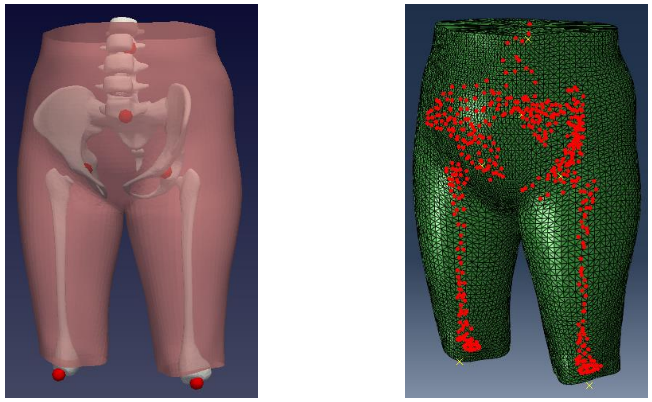

Figure 3. (Left) Skeletal geometry scaled, oriented and positioned to align with the body's joint centers. (Right) The skeletal geometry is used in conjunction with a geometric search reoutine to find the body mesh nodes that lie inside of each bone.

2.2.3 Method Assessment

There are two new features of this enhanced torso model definition process. First, the geometry source replaces point cloud input from a body scan with a mathematical body model. This both streamlines the acquisition process and provides an infinite supply of realistic body geometry based on anthropometric specifications. Second, using anatomically shaped bones and a geometric node search routine provides a skeletal structure that does not impact the volume mesh. This results both in a more realistic treatment of the skeleton and gives rise to high quality internal mesh elements. This combination means that we are able to generate a high quality body model faster and with fewer limitations compared to our previous method.

2.3 Moving Body

The advent of the pose-dependent body model provides a means to directly specify complex body motions by generating a sequence of body models in slightly different poses. Another technology developed at Max Planck Institute for Intelligent Systems (Loper, Mahmood, & Black, 2014) provides a means to drive the body model using sparse motion capture data. Using this capability and extracting vertex displacements from a sequence of body models, motion specifications can be given directly to the body finite element model. Motion specification is efficiently handled using a submodel boundary condition in conjunction with a global model built using the extracted vertex displacements. This technique even allows for mismatched meshes between the driving global model and the driven finite element body model.

Utilizing a moving body eliminates the need to model internal details of the body. However, the method provides only a one way coupling between the body and product. That is, the influence of the product does not affect the pre-determined body motion. We have experimented with three variations of the moving body method including the hard shell, soft shell and thick shell variants.

2.3.1 Hard Shell

As the name implies, the hard shell option is purely a one way coupling in which the body surface is driven directly by predetermined motions using a global model. The moving body surface is realistic, but is not influenced by interaction with a product. This method provides a realistic interface to drive product deformation with only a very simple (shell) body representation.

2.3.2 Soft Shell

A variant of the hard shell option is to define the contact interaction between the product and body as a softened contact by allowing the product to penetrate the body surface. This option may be useful where soft body tissue compression may be significant and not allowing some compliance of the body surface would provide an unrealistic interface between the product and body.

2.3.3 Thick Shell

A more complex approach is to use a thickened shell (that is actually a solid) in which the outer surface of the thick shelled body (with no product) is driven using the specified motions while the displacements of the inner surface of the thick shell is tracked. A subsequent simulation is performed using another thick shelled body interacting with a product. In this case, the inner surface of the thick shelled body is driven by the results of the first analysis. This is another way to provide some compliance of the body as it interacts with a product.

2.3.4 Method Assessment

A simple surface driven body representation eliminates the need to model internal details of the body and the simplifying assumptions that are typically associated with the bone driven body models. The moving body surface is likely more accurate than the bone driven surface because it is based on a large learning set of actual body scans. However, the surface driven body model has no, or at best little, compliance and therefore is not realistically influenced by the interaction with a product.

3. Impact

The advent of a pose dependent human shape model has had a significant impact on our ability to virtually evaluate personal care products. The shape model provides an unlimited supply of virtual product testers. The new automated user modeling process shrinks the human model acquisition time from weeks to minutes. This savings allows us to evaluate products interacting with more virtual users in a given amount of time. The utilization of anatomically shaped bone representations provides a more realistic treatment of internal body structure and improves predicted deformed shape with skeletal movement. Finally, the use of a surface driven moving body eliminates the need to simulate the complex human structure. Incorporation of this new capability has enhanced our ability to provide feedback regarding the performance of our products on a larger sample population of virtual users helping to shrink product development timelines.

4. Conclusion and Discussion

The combination of a pose-dependent human shape model in a finite element structural simulation provides an efficient means to evaluate personal care products with a realistic user sample population. The body shape model eliminates the need to acquire costly body scans and their subsequent conversion from point clouds to solid models useful for building a finite element model. By appropriately defining a coordinated series of poses, a body surface motion sequence is created and can be used to drive a virtual product user in a finite element simulation. Reduction in model complexity associated with using internal node sets in place of distinct interior regions makes body models more robust while improving their representation of internal anatomic detail.

At the time of this writing, the development of and evaluation of the new methods presented is ongoing. Two new strategies for modeling a human user of a product were described. Our next steps will include a comparison of these methods with a goal of identifying the strategy that is best suited for a particular application. The goal of this article is to communicate these new strategies as they may apply to other applications of interest to the reader.

5. References

Body Labs. (2016). *Body Labs - The body as a digital platform*. Retrieved from BODY x LABS: https://www.bodylabs.com/

Loper, M. M., Mahmood, N., & Black, M. J. (2014, Nov). MoSh: Motion and Shape Capture from Sparse Markers. *ACM Transactions on Graphics, (Proc. SIGGRAPH Asia), 33*(6), 220:1-220:13.

Loper, M., Mahmood, N., Romero, J., Pons-Moll, G., & Black, M. J. (2015, October). SMPL: A Skinned Multi-Person Linear Model. *ACM Trans. Graphics (Proc. SIGGRAPH Asia), 34*(6), 248:1--248:16.

Pieper, C. M., Woltman, G. R., Stabelfeldt, S. J., Huang, Y. H., Kathumbi-Jackson, D. R., & Kerins, J. E. (2006). *US Patent No. 7099734.*

Stabelfeldt, S. J., Huang, Y. H., Pieper, C. M., Dodge, R. N., Zenker, D. L., & Green, E. S. (2008). *US Patent No. 7373284.*

Woltman, G. R., Kerins, J. E., Kathumbi-Jackson, D. R., Huang, Y. H., Stabelfeldt, S. J., & Pieper, C. M. (2004). *US Patent No. 6810300.*

6. Acknowledgements

The author would like to thank and acknowledge Evan Lee and Flo McDavid from Body Labs, Inc. for their help and support in providing body model output to suit the specific needs of this effort.