Comparison of Vertex Influence Weight Algorithms for Repositioning of 3D Medical Models

Timothy Zehnbauer[1], Austin Mituniewicz[1], Nathan Pickle[1], Gary P. Zientara[2] and Paulien Roos[1]

[1]*CFD Research Corporation, Huntsville, AL, USA*

[2]*US Army Research Institute of Environmental Medicine, Natick, MA, USA*

Introduction

- There is a need to reposition 3D medical models to simulate realistic scenarios.
- **Rigging** computes weights for each vertex in a mesh to govern vertex movement relative to an underlying articulated skeleton [1].
- Much work has been done to rig surface meshes, but little has been done to reposition 3D volumetric finite element (FE) meshes.
- Care must be taken when repositioning labeled 3D medical models so that realistic deformation is attained.

Research Aim

Develop a fully automatic method for calculating influence weights to realistically reposition 3D medical models.

Rigging and Skinning

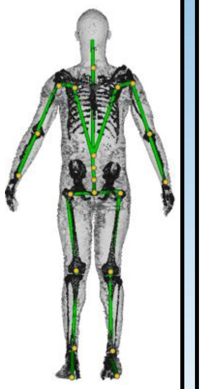
- Commonly used techniques in animation
- Computationally efficient, compatible with animation software (e.g., Unity)

Rigging:

- Underlying skeleton defined to drive mesh movement.
- Assign influence weights to each vertex for each skeleton segment.

Skinning:

- Deforming mesh based on rig.
- We use **Dual Quaternion Skinning [2]**
    - Few artifacts generated
    - Volume preservation



Original undeformed mesh displayed with rigid and soft tissues. Green lines denote segments, yellow dots denote joint center locations about which rotations are defined.

Methods

1. Start with low resolution (5mm)* articulated FE mesh with 76 labeled materials [3].
2. Rig and skin a skeleton containing motion data.
3. Calculate bone-influence weights two ways:
   - a) **Material naïve**
     - Geodesic distance of each vertex from skeleton segment [4].
     - All labeled materials treated equally.
   - b) **Material informed**
     - All rigid material weights are set to 1
     - Laplacian diffusion applied for continuous displacement field [5].
4. The mesh can then be repositioned by specifying joint angles (manually or with motion capture data), and the change in volume of the cells can be visualized.

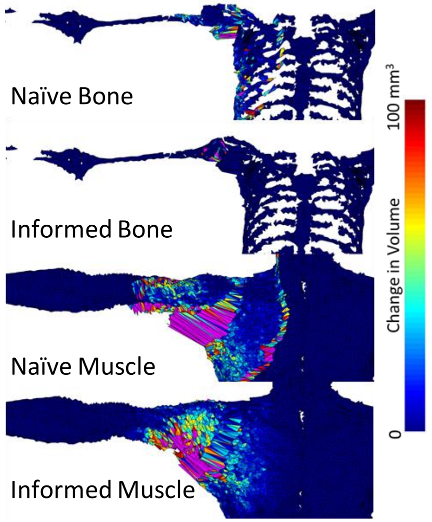
**This low-resolution mesh contains many unusual geometries*

Results

90° shoulder abduction

Individual tetrahedron deformation visualization – the change in volume from the original mesh to the deformed mesh for every tetrahedron was computed. Displayed on the right are individual tetrahedron volume changes. The average volume change of all tetrahedra are shown in the table below.

Mean Tetrahedra Material Volume Change (mm³)	Bone	Muscle
Material Naïve	0.99	3.24
Material Informed	0.32	3.20



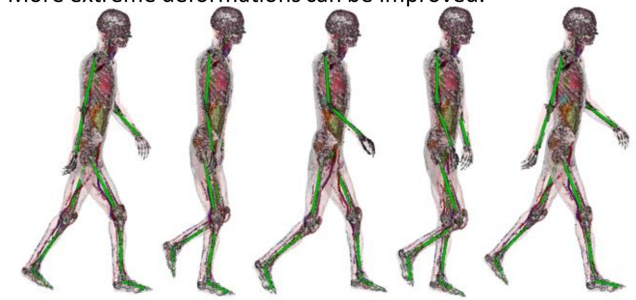
**Purple shading indicates changes in volume greater than 100 mm³. Shoulder abduction was chosen as a relatively large but common deformation.*

Conclusions

- Material-informed method successfully reduced deformation in rigid structures (e.g., bone).
    - Remaining changes in bone-labeled volume due to "stretching" of tetrahedra at the joint center.
- Greatly increases ability to deform these meshes for FE applications such as thermal analysis or projectile penetration.
- Can be applied in any mesh composed of properly labeled materials.
- Joint angles can be manually specified or driven by motion data.

Applications and Future Work

- Useful for repositioning medical models for post-processing (thermal, injury analysis).
- Mesh segmentation to avoid deformation around joint center.
- Additional material behaviors may be added.
- More extreme deformations can be improved.



Acknowledgments and References

This work is supported by the US Army Medical Research and Materiel Command under Contract Number W81XWH18C0100. The views, opinions and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

[1] Magnenat-Thalmann et. al., *Proceedings on Graphics Interface*, 1988.
[2] Kavan et. al., *ACM Transactions on Graphics*, 27(4), 1-23, 2008.
[3] Zientara et. al., *International Journal of the Digital Human,* 1(4), 389-411, 2016
[4] Dionne et. al. *ACM SIGGRAPH/SCA,* 2013
[5] Sujar et. al., *Computers & Graphics*, 74, 268*277, 2018.

Contact: timothy.zehnbauer@cfdrc.com