Mesh-based vs. Image-based Statistical Appearance Model of the Human Femur: A Preliminary Comparison Study for the Creation of Finite Element Meshes

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Statistical Appearance Models in Orthopaedic Biomechanics

- Statistical *shape* models have remarkable popularity
- *Intensity* has been integrated since it is related to bone mechanical properties
- Statistical *appearance* model combine variations of bone shape and mechanical properties
- The major issue are accurate anatomical correspondences
Importance of Correspondences

- Correspondences must be accurate both on the surface and in the volume of the bone
- Two different approaches:
  - Mesh-based: output compatible with FE simulations / smoothing can penalize correspondences
  - Image-based: non constraints due to node positioning / no iso-topology, invertible DVF

Comparison of mesh-based vs. image-based pipeline for the creation of statistical appearance models for FE simulations
Mesh-based and Image-based Pipelines

Segmented CT Images

1. Surface Mesh
2. Correspondences - Morphing
3. Statistical Model
4. Instantiation of New Meshes

Mesh-based Pipeline

5. Volume Mesh
6. FE Mesh Quality

Image-based Pipeline

2. Correspondences - Registration
3. Statistical Model
4. Instantiation of New Images
Image to Surface Mesh

1. Surface Mesh
2. Mesh Morphing
3. Statistical Model
4. New Meshes
5. Image Registration
6. Statistical Model
7. New Images
8. Volume Mesh
9. FE Mesh Quality

- VTK marching cubes
- VTK decimation
- VTK smoothing
- MRFSurface
RBF Morphing
Correspondence Detection

Polyaffine Log-Demons Correspondence Detection

Polyaffine registration

Log-Demon regularization

Statistical Models

Mesh-based pipeline

Image-based pipeline

Statistical shape model

Statistical intensity model

Statistical appearance model

\[ b = \begin{pmatrix} W_s b_s \\ b_g \end{pmatrix} = \begin{pmatrix} W_s \Phi_s^T (x - \bar{x}) \\ \Phi_g^T (g - \bar{g}) \end{pmatrix} \Rightarrow b = \Phi_c c, \Phi_c = \begin{pmatrix} \Phi_{c,s} \\ \Phi_{c,g} \end{pmatrix} \]

Creation of New Instances

Mesh-based pipeline

Intensity
\[ \tilde{g} = \bar{g} + \Phi_g \Phi_{c,g} \bar{c} \]

Shape
\[ \tilde{x} = \bar{x} + \Phi_s \mathcal{W}_s^{-1} \Phi_{c,s} \bar{c} \]

Image-based pipeline

Image to Volume Mesh

1. Surface Mesh
2. Mesh Morphing
3. Statistical Model
4. New Meshes
5. Volume Mesh
6. FE Mesh Quality
FE Mesh Quality

> Metric of *volume*: Jacobian

> Metric of *size*: Edge Ratio

> Metric of *shape*: Minimum Angle
Statistical Appearance Models

Results

157 left femur CT images

Compactness of the statistical appearance models

<table>
<thead>
<tr>
<th>Compactness</th>
<th>Mesh-Based Pipeline</th>
<th>Image-Based Pipeline</th>
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</thead>
<tbody>
<tr>
<td>50%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>75%</td>
<td>6</td>
<td>27</td>
</tr>
<tr>
<td>90%</td>
<td>40</td>
<td>86</td>
</tr>
<tr>
<td>100%</td>
<td>157</td>
<td>157</td>
</tr>
</tbody>
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Shape Model | 5 min\(^1\) | 5 hrs\(^2\)
Intensity Model | 2 min\(^1\) | 1.5 hrs\(^2\)
Appearance Model | 9 min\(^1\) | 6.5 hrs\(^1\)

\(^1\)Processor: Intel Core Duo, E8500 @ 3.16GHz. RAM: 8GB
\(^2\)Processor: Intel Xeon CPU, X5550 @ 2.67GHz. RAM: 48GB

Creation of 30 new instances for each model with 90% variation
FE Mesh Quality
Results

Jacobian

Edge Ratio

Minimum angle

<table>
<thead>
<tr>
<th>Mesh-based</th>
<th>Image-based</th>
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<td>28/30</td>
<td>30/30</td>
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- Meshes from the mesh-based pipeline
- Meshes from the image-based pipeline
Conclusion

> Preliminary study on mesh-based vs. image-based approach

> Mesh-based pipeline:
  — Low quality of the mesh tetrahedrons
  — More compact model, iso-topological meshes

> Image-based pipeline:
  — DVF inversion issue, no iso-topological meshes, computational expensive
  — High quality of the mesh tetrahedrons
Outlook

> Validation of correspondence detection and models
> Merge strength of the two methods
> Compare the implications for FE simulations