Simultaneous segmentation and correspondence improvement using statistical modes

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Functional Endoscopic Sinus Surgery

• What is it?
  • Minimally invasive procedure
  • Chronic sinusitis, nasal polyps, etc.

• 600,000 procedures in the US per year\[1\]
• 5-7% result in minor complications\[2\]
• ~1% result in major complications\[2\]
Sinuses & Nasal Airway: Complex structures with thin boundaries

Fovea ethmoidalis: separates the ethmoid cells from the anterior cranial fossa
Thickness: ~0.5 mm[3]

Boundary between the sinuses and the orbit
Thickness: ~0.91 mm[4]

Enhanced Endoscopic Navigation

Pre-op CT → Labeled Template → Deformable Registration → Intra-op video

Registration (ICP\(^{[13]}\)/IMLP\(^{[14]}\)/IMLOP\(^{[15]}\)/V-IMLOP\(^{[16]}\)/etc.)

Structure from motion

References:


Segmentation & Statistics

Set of CTs

Statistics
Our paper: Better segmentation & statistics

Segmentation

Before

After

Statistics

Left Maxillary Sinus
Leave One Out Analysis

Mesh Quality

Before

After
Statistical Shape Model (SSM)\(^5\)

\[
\begin{align*}
\bar{V} &= \frac{1}{n_s} \sum_{i=1}^{n_s} V_i \\
\Sigma &= \frac{1}{n_s} \sum_{i=1}^{n_s} (V_i - \bar{V})^T (V_i - \bar{V}) \\
\Sigma &= \begin{bmatrix} m_1 & \cdots & m_{n_s} \end{bmatrix} \begin{bmatrix} \lambda_1 & \vdots & \lambda_{n_s} \end{bmatrix} \begin{bmatrix} m_1 & \cdots & m_{n_s} \end{bmatrix}^T
\end{align*}
\]

Correspondence Improvement\textsuperscript{[8]}

Project shape onto the modes
\[
b_i = m_i^T (V_i - \bar{V})
\]

Compute estimate shape
\[
V = \bar{V} + \sum_{i=1}^{n_s} b_i m_i
\]

Move vertices of original shape along the surface toward the corresponding vertex on estimated shape\textsuperscript{[8]}

Assumption

- High accuracy segmentations
- Segmentation improvement
- E.g.: Using gradient vector flow (GVF) snakes\textsuperscript{[6][7]}
  - Use gradient in corresponding CT image
  - Move mesh vertices toward structure boundaries
- Correspondences between shapes
- Lost during segmentation improvement


Simultaneous segmentation and correspondence improvement
Constrained segmentation improvement

- Using GVF
  - Move vertices toward large gradients in image to obtain new surface, $\phi$
  - Estimate $\phi$ using pre-existing SSM
  - Slide vertices on $\phi$ along the surface toward corresponding vertices on estimated shape
Simultaneous segmentation and correspondence improvement

Deformed Meshes → PCA → SSM → Constrained GVF → Improved Segmentation → Corr Up

$P = 5$

$Q = 3$

5 iterations
Results

From 52 publicly available CTs [9][10][11][12]


Results: Segmentation

Red contour: Segmentation via label transfer using deformable registration

Blue contour: Hand-labeled gold standard

Green contour: Improved segmentation using our method
Results: Segmentation

Segmentation errors compared against hand-segmented gold standard computed using the Hausdorff distance metric.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean Error ± Std. Dev. (mm)</th>
<th>Max Error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformable registration</td>
<td>0.3327 ± 0.3147</td>
<td>2.338</td>
</tr>
<tr>
<td>GVF</td>
<td>0.1135 ± 0.1316</td>
<td>1.1548</td>
</tr>
<tr>
<td>GVF + SSM (our method)</td>
<td>0.0985 ± 0.128</td>
<td>1.0364</td>
</tr>
</tbody>
</table>
Results: Correspondence

Left Maxillary Sinus
Leave One Out Analysis

Mean residual surface errors between left out shape and its estimate (mm)

- Deformable Registration
- Gradient Vector Flow (GVF)
- GVF + SSM (our method)

Number of modes
Results: Mesh Quality

Segmentation improved using GVF

Segmentation improved using our method

Triangle Quality
Conclusion

• Our method improves segmentation while maintaining correspondences
• Demonstrate improved segmentation and correspondence

Our shape model contains more accurate information

Our shape model is able to estimate a new shape accurately
Thank you!

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cisst Developers

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References


Questions?

Code will be available on github soon!