Optimizing Design with Extensive FEA Data

A Case Study using Realistic Vacuum-Assisted Biopsy Cutting Simulations

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Grand Challenge

Today, we are facing extensive and expensive product cycles of medical device development

Early initiation of animal trials without sufficient understanding of parameter selections

“We believe that these limitations can be overcome through advancements in data-driven and simulation-based medical device design and manufacturing - a research topic that draws upon and combines emerging work in the areas of Regulatory Science and Big Data.“

What are We Interested in?

- Accurate, high-resolution simulation
- Many simulation runs

How can we better explore these datasets and find desired design solutions?
The Solution We Came Up with: Design by Dragging

Design by Dragging:

- A software interface to enable data-driven simulation-based design
- Pre-computed design space that integrates all simulation datasets
- The design exploration is as direct as possible (dragging) and is guided by the user intent

Exploring the Design Space

Red Dot = A specific sample (design configuration)
Green Line = Similarity (Relative Distance) between two samples
Transition between two samples

“Inverse Design”

Change design output parameters/fields via direct manipulation, immediately display the closest matching design configuration.
Inverse Design Demo
A Case Study with Complexity
The Tissue-Cutting Process

Source of this video: www.bupa.co.uk
The Tissue Cutting Simulation
Tissue Cutting Model Developed in Collaboration with ANSYS

### Design Space Population

**Design Variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translation Cutting Speed ($v_a$)</td>
<td>N = 3 (10, 50, 100)</td>
</tr>
<tr>
<td>S-P Ratio (R)</td>
<td>N = 20 (0 - 10)</td>
</tr>
<tr>
<td>Tissue Type (B)</td>
<td>N = 3</td>
</tr>
<tr>
<td>Rotary motor choice ($M_r$)</td>
<td>N = 5 (Maxon DC motors)</td>
</tr>
<tr>
<td>Total Samples</td>
<td></td>
</tr>
</tbody>
</table>

**Performance Attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total procedure time</td>
</tr>
<tr>
<td>Tissue sampling rate</td>
</tr>
<tr>
<td>Max. motor overload factor</td>
</tr>
<tr>
<td>System Weight</td>
</tr>
<tr>
<td>Component Cost</td>
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</tbody>
</table>

These **900** datasets are used to sample a design space with **$10^6$ possible solutions**.

*If an increment of 0.1 for the design variables is used.*
Pre-Computation Process

Simulation Module
- Design Input Parameters
  - Tissue-Cutting Simulation (FEA)
    - Tissue Reaction Forces
  - Motor & Device Performance Evaluation (Equation-based)
    - Stress on Tissue
      - Performance Attributes
    - High-Efficiency Data Form
      - Warp computation

Post-Processing Module
The Design Space Loaded in DBD
Inverse Design Use Cases
Inverse Design: Moving a leading edge

Current design ($v_a = 50, R=0.7$): too much axial tissue displacement

New design: increase R to 4
Inverse Design: Solving ‘dry tap’

Step 1: Locating the dry tap: cutting adipose tissue with low cutting speeds

Step 2: Trigger previews at a desired area

Step 3: Reach a new design
Inverse Design: Narrowing a High Stress Area

- Presume that a more concentrated high-stress area surrounding the cutter-tissue contact surface would produce a cleaner cut
- Looking at an early cutting stage: time step = 7/21
- Initial design: $R=0.4$, $v_a = 50$
- Move the leading edge of the high stress area (red) inward
- New design: $R = 0.6$, $v_a = 10$ (much lower motor requirements!)
Conclusions

• Design based intensive and massive simulation data
• The importance of human interaction and creativity
• Future directions:
  – Scale up
  – More applications
Acknowledgements

• Our Research Team
  – Prof. Art Erdman
  – Prof. Dan Keefe
  – Dane Coffey

• ANSYS:
  – Ashutosh Srivastava
  – Marc Horner
  – Mark Swenson

• Breast Center at U of Minnesota
  – Michael Nelson, MD

• Minnesota Supercomputing Institute
• National Science Foundation (IIS-1251069)
• National Institutes of Health (1R01EB018205-01)