Optimizing Design with Extensive FEA Data

A Case Study using Realistic Vacuum-Assisted Biopsy Cutting Simulations

Chi-Lun Lin, Dane Coffey, Daniel Keefe, Arthur Erdman
University of Minnesota

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Data Is Getting Bigger and Bigger

Big Data

Traditional Data

Dataset

Increases in Data Instance Size

Increases in Number of Data Instances
How Can We Better Explore the Big Data?

Design by Dragging

- Smart search
- Large, pre-computed design space
- As direct as possible, as natural as possible user interactions

Direct Manipulation on Visualization

Change design **output** parameters/fields via direct manipulation, immediately display the closest matching design configuration.

“move this over here” (by Click & Drag)

“preview bubbles”
How is the Direct Manipulation Enabled?

Red Dot = A specific sample (design configuration)
Green Line = Similarity between two samples
Transition between two samples
Direct Manipulation Demo
Case Study: VAB Device Design

- Cutting Speeds
- Different breast tissue properties
- Cutting forces required
- Device Performance
The Tissue-Cutting Process

Source of this video: www.bupa.co.uk
The Tissue Cutting Simulation
(Abaqus Explicit Dynamic Model)
Tissue Cutting Model Developed in Collaboration with ANSYS (Explicit STR)

Pre-Computation Process

Motor simulation (equation-based)

Motor Selection

Rotational Cutting Speed

Translational Cutting Speed

Tissue properties

Motor Overload Factor

System Weight

Component Cost

Total Procedure Time

Tissue Sampling Rate

Cutting forces
**Design Space Sampling**

<table>
<thead>
<tr>
<th>Design Input Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Translation Cutting Speed ($v_a$)</td>
<td>$N = 3$</td>
</tr>
<tr>
<td></td>
<td>$(10, 50, 100$ mm/s$)$</td>
</tr>
<tr>
<td>S-P Ratio (R)</td>
<td>$N = 20$</td>
</tr>
<tr>
<td></td>
<td>$(0 - 10)$</td>
</tr>
<tr>
<td>Tissue Type (B)</td>
<td>$N = 3$</td>
</tr>
<tr>
<td>Rotary motor choice ($M_r$)</td>
<td>$N = 5$</td>
</tr>
<tr>
<td>Total Samples</td>
<td>900</td>
</tr>
</tbody>
</table>

900 design points to sample a design space with $10^6$ possible solutions*

*If an increment of 0.1 for the design variables is used
Design Space Sampling

- 900 datasets are stored in a high-efficiency data form (NetCDF)
- *Transitions* are pre-computed
- *Similarities* are computed in real-time

\[ d(A, B) = \sum_{i=1}^{n} \sqrt{w_i \cdot (D(A_i, B_i))^2} \]
Direct Manipulation Use Cases
#1: Moving a leading edge

Current design ($v_t = 50, v_r=35 \text{ mm/s}$): too much axial tissue displacement

- **Step 1**: Output Radar Chart
  - Current design: $v_t = 50, v_r=35 \text{ mm/s}$
  - Output Radar Chart
    - Higher cutting speeds
    - Only increases rotational cutting speed

- **Step 2**: Output Radar Chart
  - Preview for new leading edge
    - Current leading edge
  - Right-click for design suggestions

- **Step 3**: Output Radar Chart
  - Moved into the preview bubble
  - New design: increase $v_r$ to 200 mm/s

### Diagrams:
- **Max Motor Overload**
- **Procedure Time**
- **Component Cost**
- **Tissue Sampling Rate**
- **Mechanical System Weight**

### Radar Chart:
- Current design ($v_t = 50, v_r=35 \text{ mm/s}$)
- Output Radar Chart
  - Tool overload
  - Procedure time
  - Component cost
  - Tissue sampling rate
  - Mechanical system weight
#2: 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: $v_r=20$, $v_t = 50$
- Move the boundary of the high stress area (red) inward
- New design: $v_r = 6$, $v_t = 10$ (**much lower motor requirements!**)
- SP Ratio increases from 0.4 to 0.6
#3: Solving ‘dry tap’

Dry tap occurs when cutting adipose tissue with low cutting speeds.

Trigger previews at a desired area.

New design.
Conclusions

• A new way to find optimal solutions in a pre-computed, large-scale design space
• Emphasizing the importance of human interaction and user knowledge input
• Created use cases for a realistic tissue-device interaction problem
• Future Opportunities:
  – Scale up
  – Learning by incorporating more device design examples (heart valve, stent, etc)
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