FiberFind: Machine learning-based segmentation and identification of individual fibers in μCT images of fibrous media

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Wesley DeBoever, Bruker μCT
UNDERSTANDING NONWOVENS USING MACHINE LEARNING

<table>
<thead>
<tr>
<th>GeoDict 2018:</th>
<th>Existing methods measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>- fiber diameter distribution (FiberFind)</td>
<td></td>
</tr>
<tr>
<td>- fiber orientation (FiberFind)</td>
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<tr>
<td>- pore size distribution (PoroDict)</td>
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<th>GeoDict 2019:</th>
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<tr>
<td>- statistics of the above better than in 2018</td>
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OVERVIEW OF SAMPLE STRUCTURES

- Aim: Quantify differences in nonwoven samples

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Resolution</th>
<th>Physical dimensions</th>
<th>Voxel dimensions</th>
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<tbody>
<tr>
<td>A</td>
<td>2.4µm</td>
<td>43.9 x 11.6 x 4.1 mm³</td>
<td>18,310 x 4,816 x 1,704</td>
</tr>
<tr>
<td>B</td>
<td>2.7µm</td>
<td>42.2 x 10.9 x 4.8 mm³</td>
<td>15,619 x 4,032 x 1,796</td>
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- Scanned by Bruker microCT on SkyScan 1272
- Analyzed by Math2Market using GeoDict
## Sample A – 2D View

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**Sample B – 2D View**

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SAMPLE A – 3D view

Voxel dimensions
18,310 x 4,816 x 1,704
SAMPLE B – 3D view

Voxel dimensions
15,619 x 4,032 x 1,796
HOW THE TECHNOLOGY WORKS

1. Generate synthetic GeoDict models that look similar to the real material to be analyzed.

2. Models contain full information: Exact geometry for each fiber is known.

3. Train Neural Network (NN) on synthetic material models.

4. Use Neural Network. Apply trained Neural Network to μCT scan to label centerline of fibers.

5. Postprocess Centerlines into analytic representations.
Training Data: Use GeoDict’s fiber modelling capabilities:

- Model 10 random digital siblings (512x512x256 Voxels) as training data
- Vary fiber curvature, orientation, length and diameter
- Corresponds to ~1 billion solid voxels as training data points
TRAINING PHASE OF NN

Dozens of binarized GeoDict models  
Neural Network  
Dozens of labeled GeoDict models
Training: NN learns to label centerlines from input and output
- input: GeoDict Model: binary image
- output: GeoDict Model: labeled fibers

Usage: NN predicts centerlines from input
- input: μCT data: binary image
- output: μCT data: labeled fibers
### Fiber Identification Challenges

**Sample preparation:**
Scan 5 cm x 1 cm, 2.4 µm resolution
- 6 µm resolution did not resolve fibers well enough
- Fibers were thinner than expected

**Very large data sets**
- Up to 18,310 x 4,816 x 1,704 ~ 150 billion voxels
- Required 1TB memory hardware for full analysis
- Required many optimizations in FiberFind algorithms

**Varying fiber diameters and shapes**
- Round, trilobal, and hollow fibers
- Neural networks (currently) trained only on round fibers

[Image: Low resolution and Motion blur]
SAMPLE B WITH SOME HIGHLIGHTED FIBERS
COMPLETE WITH SOME HIGHLIGHTED FIBERS
SAMPLE B – TRACKING SINGLE LIGHT-BLUE FIBER
Density Map (Cloudiness)
Fiber cross-sections

Sample A

Round / Trilobal / Hollow

Sample B

Round
FIBER DIAMETER DISTRIBUTION

Sample A

Not analyzed due to non-circular fiber cross-sections

Sample B

Average fiber diameter

24.6 µm

Standard deviation

4.6 µm
Sample B

Average Fiber Length: 4.4 mm
FIBER ORIENTATIONS – SAMPLE A

<table>
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<tr>
<th>XY</th>
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<th>YZ</th>
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<td><img src="image1.png" alt="Graph 1" /></td>
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View of a section of the surface in the direction of the X axis.
# Fiber Orientations – Sample B

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View of a section of the surface in the direction of the X axis.
(Long)-Glass Fiber Reinforced Polymer (GFRP):

- Glass weight percentage 30%
- Polypropylene Matrix
- Fiber length of 4-6 mm
- Fiber diameter 15-30 µm

GFRP are used in various applications, e.g.

- Aerospace/automotive body components
- Hydrogen tanks

µCT-scan:
Ca. 6mm x 6mm x 3.2mm
2µm voxel resolution
SEGMENTATION

From stack of gray value slices

To 3-D segmented image
IDENTIFIED FIBERS ON WHOLE CT SCAN

Input: Segmented CT scan

Output: Labeled CT scan
FIBER DIAMETER AND LENGTH ANALYSIS

- Fiber diameter distribution
  X-Axis: Diameter
  Y-Axis: Volume Fraction
  With Gaussian distribution fit

- Fiber length distribution
  X-Axis: Fiber Length
  Y-Axis: Relative Count Probability
**MACHINE LEARNING-BASED BINDER IDENTIFICATION (TORAY CARBON PAPER)**

- **Challenges:**
  - Ground truth to train the network is not easily available
  - Generated training data with GeoDict
  - Applied trained network successfully to CT-Scan

**INPUT:** segmented µCT-Scan of fibers (white) + binder (also white)

**OUTPUT:** labeled fibers (white) and identified binder (red)
**CONCLUSION**

- Neural networks trained to segment artificial microstructures generalize to μCT-scans of real materials.
- Identification of individual fibers in different types of material types works.
  - Allows wide range of statistics on the fibers.
- Approach can easily be extended to other materials using the powerful structure generators available in GeoDict.
  - Currently looking at applying this for grains.
  - We are open for new challenges – see us at our booth!
THANK YOU!