Machine Learning-based segmentation of individual Fibers in Micro-CT Scans with GeoDict

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Aims

Fibrous structures are present in many materials, including non-woven filter media used for filtration, carbon-fiber reinforced plastics or glass-fiber reinforced plastics used in mechanical applications, or gas-diffusion layers used in fuel cells. Spatial distribution, orientation, length, curvature and center line of fibers in materials like these are essential characteristics required in modern material design. Being able to analyze these properties from micro-CT scans is highly important to create precise models of existing materials. We propose a machine learning-based algorithm to identify and extract the individual fibers in segmented 3D images to be able to fully characterize them.

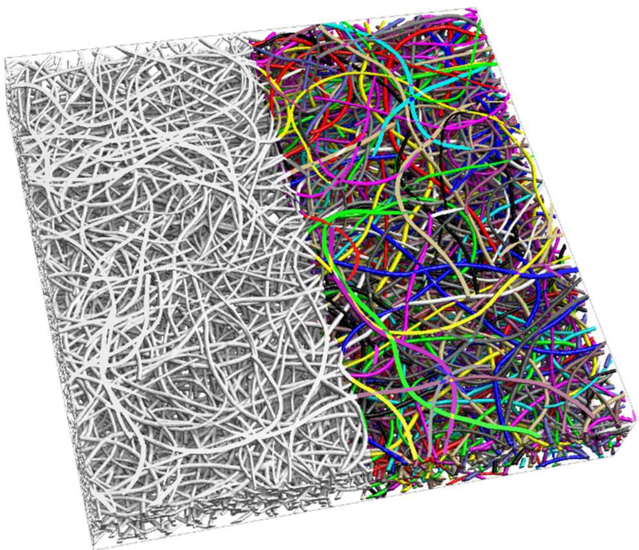
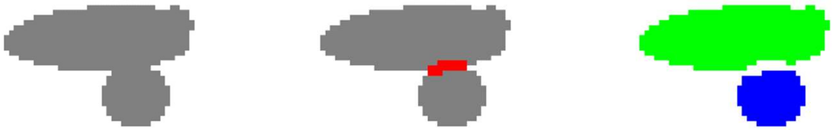


Figure 37: Structure model of a nonwoven material and the segmented fibers in fifteen different colors. In the right half, the single fibers have been assigned to one of fifteen different colors. Fibers that touch share the same color and correspond to connected components in the structure.

Method

Many approaches to extract the statistics of the fibers from micro-CT scans focus on processing the skeleton of the fibrous structure and removing the crossings that form at fiber contact points. [1,2,3] With increasing number of contacts, the complexity of the skeleton grows dramatically, limiting the success of this approach. We propose a machine learning based algorithm to identify and extract the individual fibers in segmented 3D images to be able to fully characterize the fibers and the overall composition of a material. Machine learning based on deep neural networks requires massive amounts of training data, in our case known fiber contacts. One approach could be to label these manually. However, this is not feasible for 3D data sets. Instead, we use GeoDict's [4] fiber structure modelling and scripting capabilities to generate training data sets, which consist of voxelized 3d fiber models and known fiber contact voxels.
After the neural network is trained it can be applied directly to a segmented micro-CT scan to identify the contact voxels between connected (undersegmented) fibers. These voxels are labeled differently from the remaining solid voxels in the micro-CT image.
Afterwards, the labeled contact voxels (red voxels in Figure 2b) are removed from the segmented image to separate the fibers and therefore simplify the topology of the fibrous structure. In the final step, the connected components are analyzed (Figure 2c) and a skeleton



a b c

based approach is used to obtain the centerline of individual fibers. These centerlines are then traced to obtain an analytic geometric description of the material.

Results

We applied our method to a nonwoven micro structure that has not been shown to the neural network before. The structure is generated from an analytic model containing 499 fibers. The neural network achieved a decomposition into 467 connected components. In this example all bond points were detected.
The remaining error occurs not because contact points are not detected at all, but in some cases

Figure 2: Fiber contact/bond detection and resolving.

not all voxels of bond points were labeled correctly. These remaining connections between fibers results in the mismatch between number of fibers and connected components. For the future we want to improve the quality of the bond point detection to improve the separation and implement postprocessing steps to remove remaining connections.

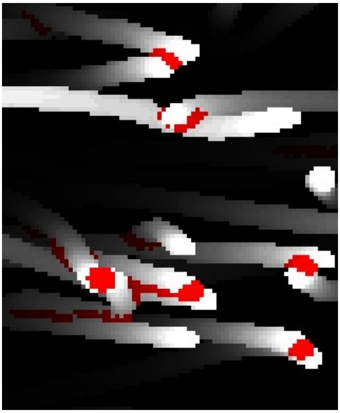


Figure 3: Example of detected fiber bond points in a microCT image. The image shows fibers in white, background in black and the labeled bond points in red. The colors are attenuated with increasing depth simulating an SEM image**.**

For further experiments we identified the individual fibers an micro-CT scan of a glasfiber reinforced composite provided by Bruker MicroCT [5] and obtained 1641 connected components. This number includes fragments of fibers at the domain boundary that are currently not processed further. The result is visualized below.

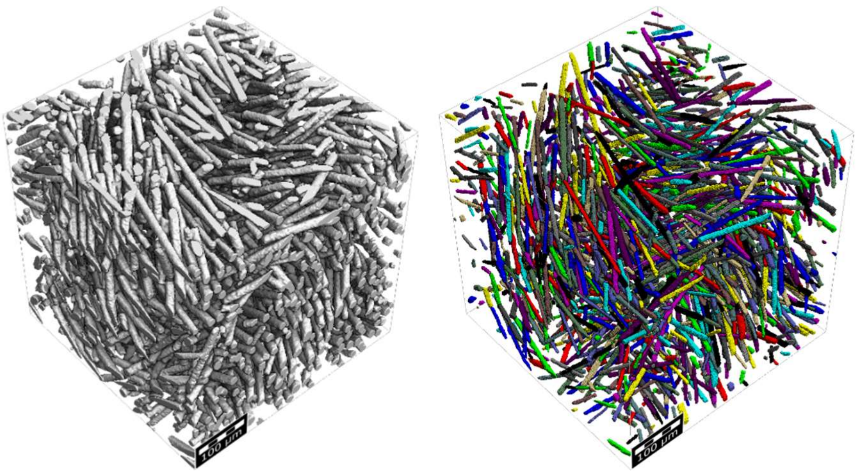


Figure 4: Glas fiber reinforced composite scan provided by Bruker MicroCT (left), individual fibers (right)

Conclusion

The existing algorithms included in GeoDict to analyze fiber diameter, fiber orientations and fiber curvature are already useful when trying to create virtual twins of fibrous materials. With the capability to extract individual fibers from micro-CT scans it is possible to analyze fibrous structures in a very detailed manner and create even more precise models with less manual work. For future developments we want to extend the capabilities of machine learning based micro-CT analysis to work on even more types of fibrous materials. Additional ongoing experiments include identification of fibers in binder-infused materials.

References:

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