Characterization of stone wool using fiber tracking based on local orientation

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Introduction

Stone wool is material made of many tiny fibers interwoven in complex patterns. In order to understand the mechanical properties of stone wool, we need to have a set of quantitative measures we can use to describe the material. Since stone wool consists of fibers, some important characteristics are the radius, length, and local orientation of these.

This project aims to construct methods to estimate these parameters from X-ray CT scans of small stone wool samples.

Method

The estimation method is based on a two stage procedure, as shown in the flowchart below:

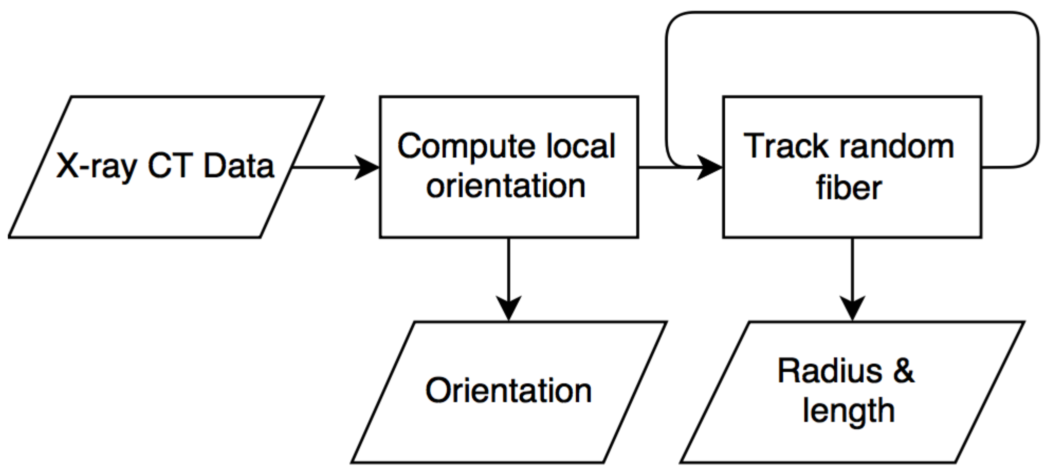

Fig. 1: Flowchart describing the method

First, the local orientation for the entire volume is computed using a structure tensor method. The structure tensor, which is a Gaussian smoothed outer product of the image gradients, gives information about the change of intensity in a local region around some point. By inspecting its eigenvectors – specifically the smallest one, see Fig. 2 – we can gain knowledge about the local orientation at every point.

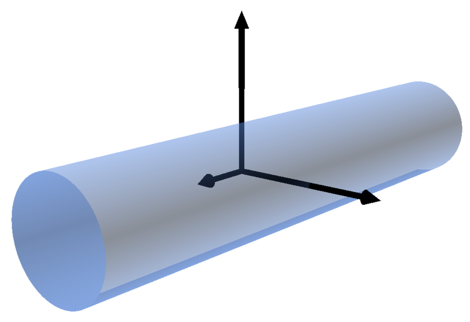

Fig. 2: Structure tensor eigenvectors for a point in a fiber.

Knowing the local orientation for the fibers, we can then, given a suitable seed point, track a fiber by following the orientation vectors. At each step, a fiber cross section is analyzed in order to track the fiber radius, see Fig. 3. The fiber length can be found as the length of the tracked path.

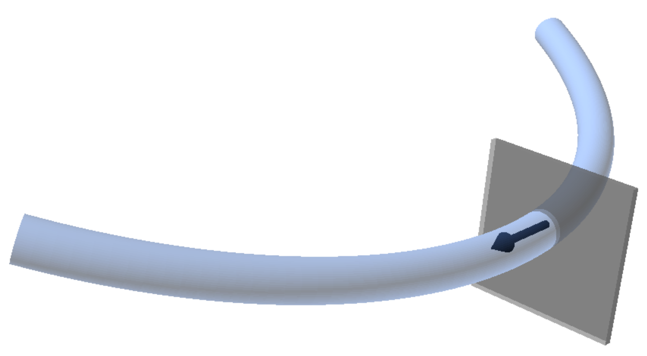

Fig. 3: Illustration of how the tracking method extracts fiber cross sections at each step.

Currently, we repeatedly choose a random seed point within a random fiber and then perform the tracking. In order to not skew the statistics, we use the median radius (since the fibers rarely change in thickness), and duplicate fibers are removed from the tracking results.

The tracking method is also augmented by using tensor shape measures inspired by those used in DT-MRI tractography. This allows the algorithm to detect regions with low anisotropy where the local orientation is not certain. Lastly, if the fiber was found in the extracted cross section, the tracking step is adjusted to move toward the fiber center.

Results

To test the performance of the method, it was run on an X-ray CT scan of a 762.3 x 762.3 x 400.8 µm stone wool sample. The resulting orientation estimation is shown in Fig. 4 and Fig. 5.

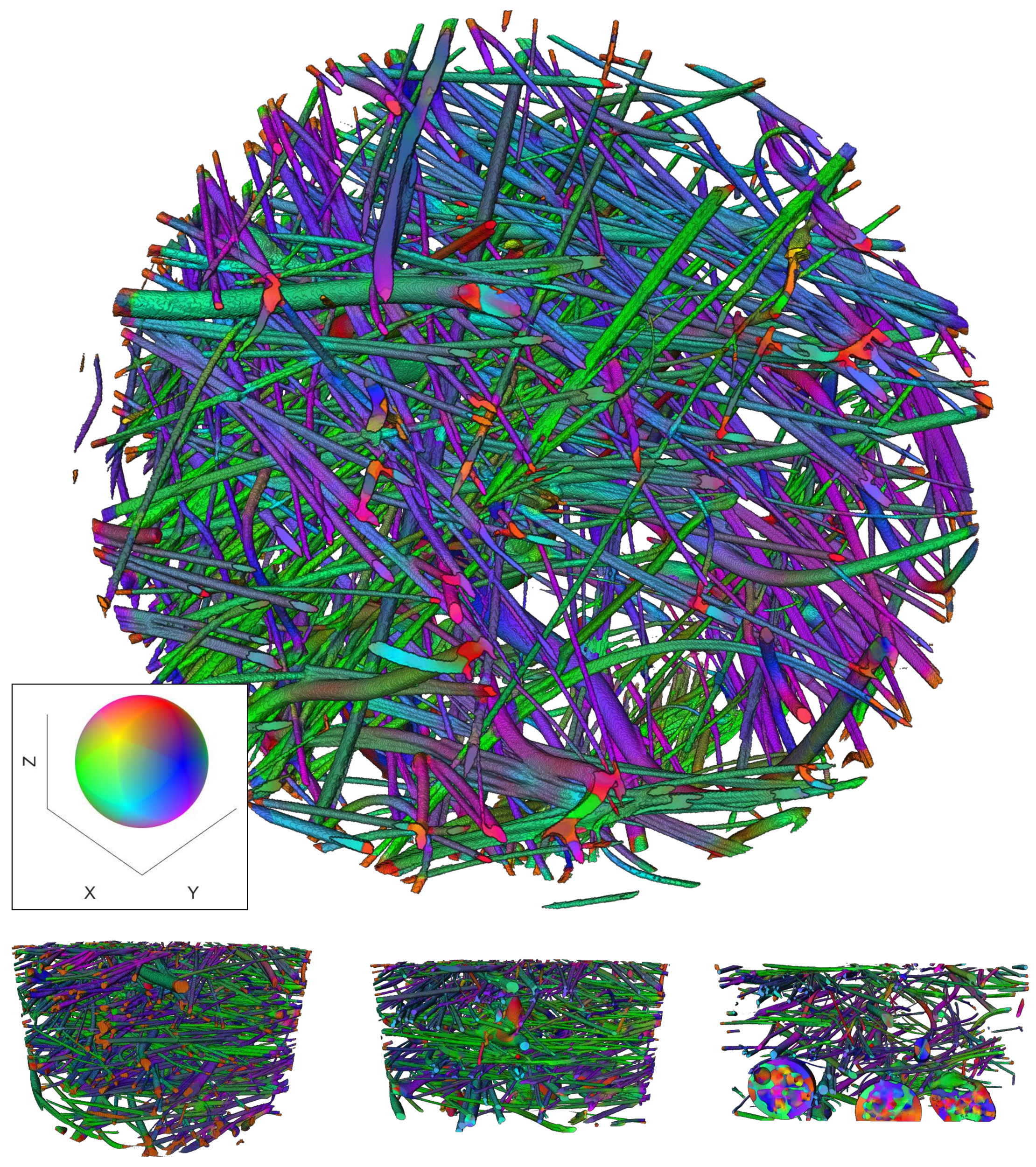

Fig. 4: Stone wool volume colored according to local orientation. A top- and side view is shown.

The analysis shows that the fibers tend to orient themselves in the XY-plane, with one azimuth direction being more dominant than others. Also, the method itself seems to work quite well for fibers, but breaks down when inside 'shots' (large spherical droplets) or other impurities.

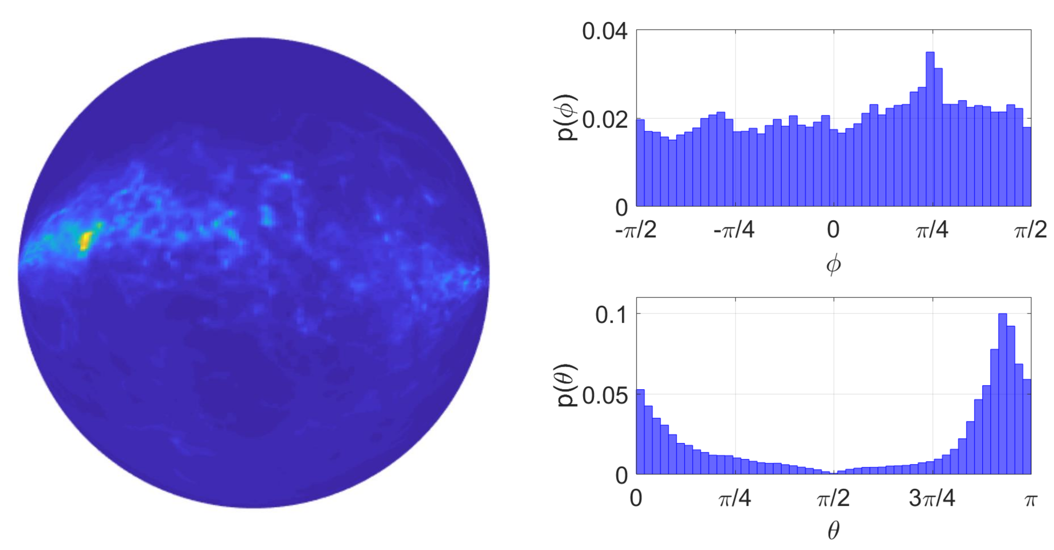

Fig. 5: Left: Orientation vectors projected on the unit sphere. Right: Orientation histograms for the stone wool sample.

The segmentation resulting from the fiber tracking is shown in Fig. 6, with 549 fibers tracked in total. Overall, the segmentation seems to correspond well with the original fibers, but it is clear that not all fibers have been tracked, and the method has some difficulty with material impurities.

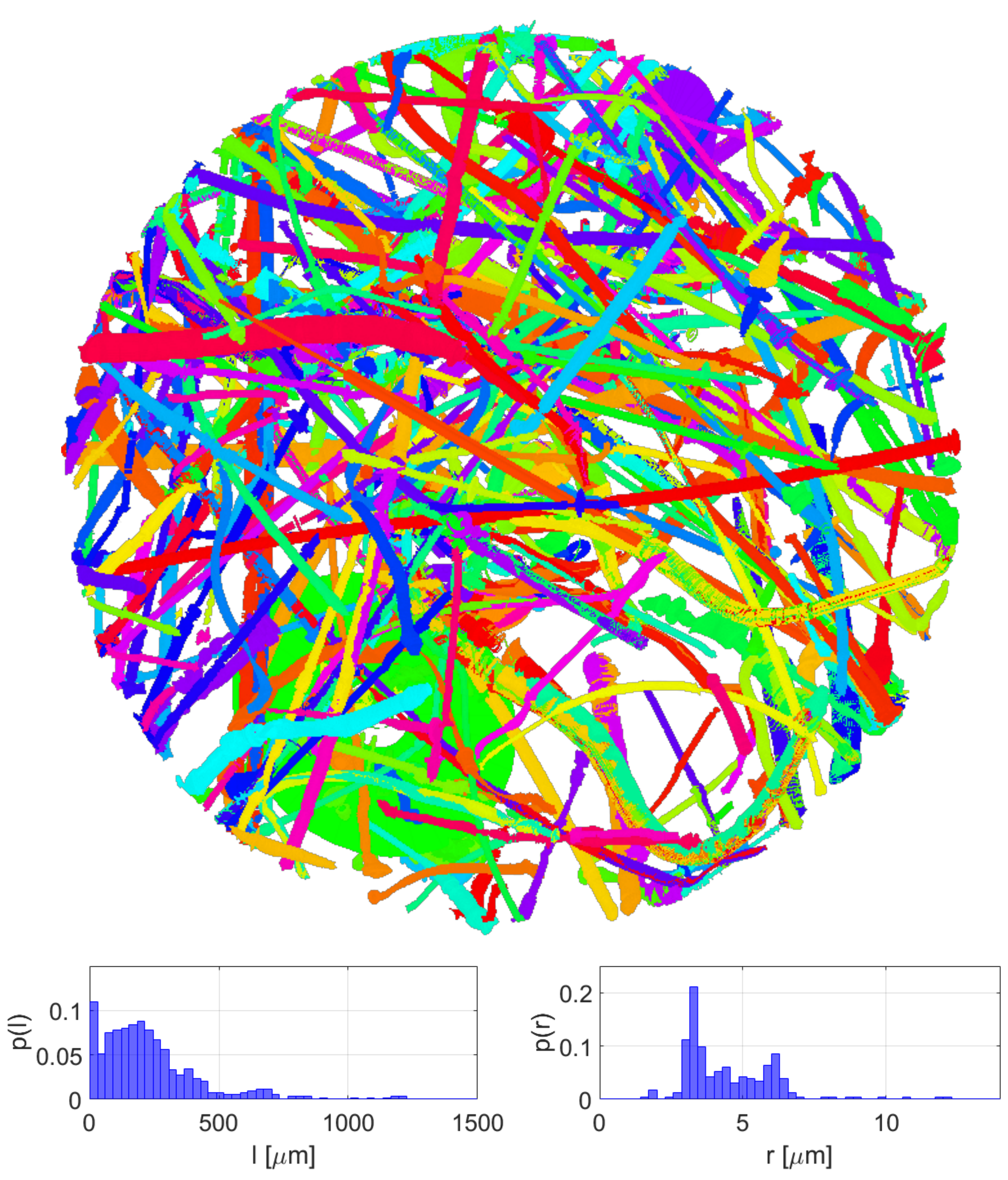

Fig. 6: Top: Fiber segmentation based on fiber tracking. Bottom: Length- and radius histograms.

Validation

In order to validate the method, three artificial fiber networks were generated, where the fiber properties of interest are known. The method was then run on the data and the results (Fig. 7) were compared with the ground truth (Fig. 8).

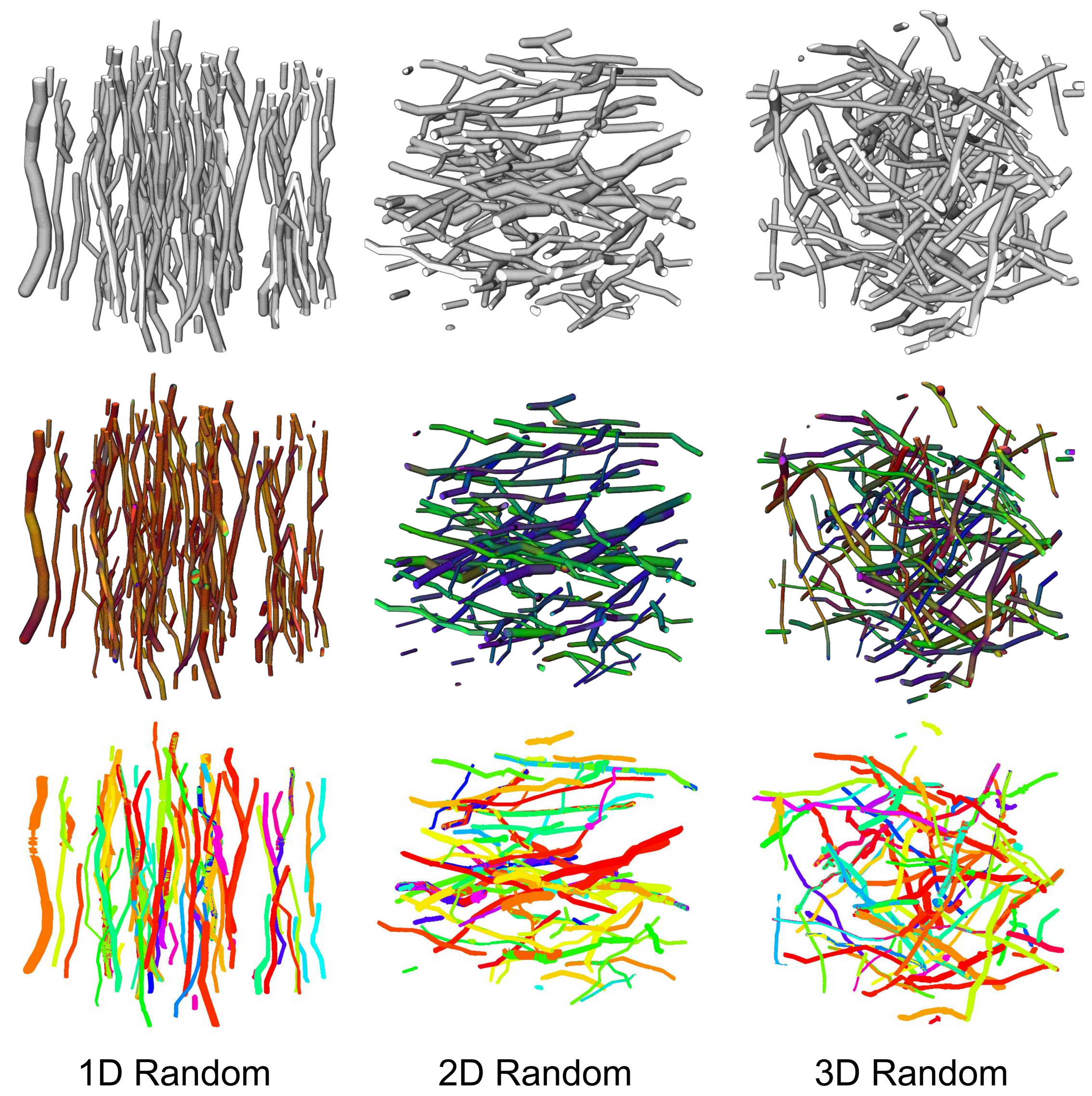

Fig. 7: Middle: Fibers colored according to their local orientation. Bottom: Segmented fibers based on tracking results.

As can be seen in Fig. 8, the estimated orientation corresponds closely to the ground truth, which is also apparent in Fig. 7. The radius- and length estimations have some outliers, but otherwise seem to follow the trend of the ground truth.

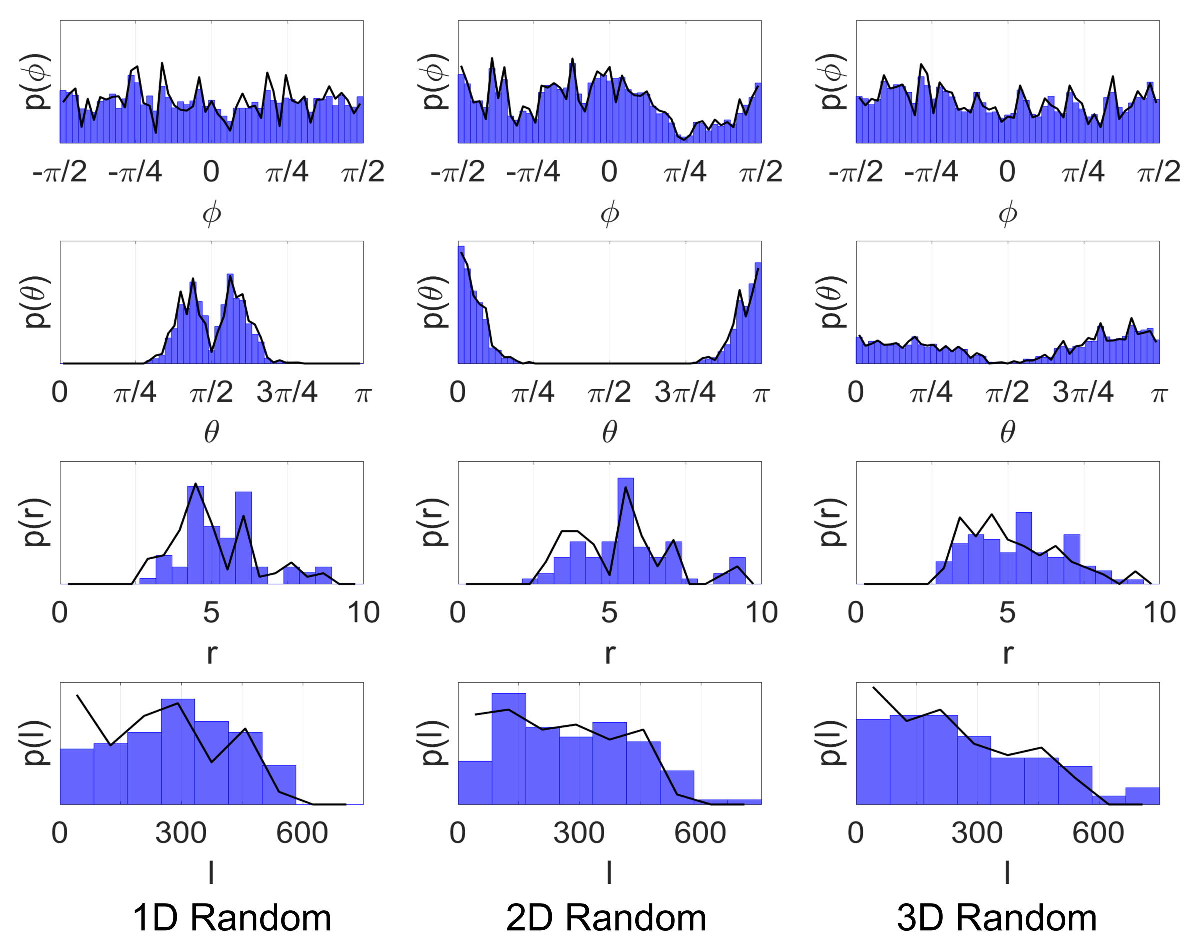

Fig. 8: Method results compared to the known ground truth for each artificial network. The histogram shows the estimated distributions, while the black line shows the ground truth.

In general, the outliers tend to be an under-representation of the short and/or thin fibers, which, given that the sampling method simply picks random points in the volume, is not unexpected.

Further work

So far, the method for orientation estimation procedure has been implemented and is working. The tracking method, while promising, still have some major difficulties which are:

- Dealing with regions where fibers touch
- Dealing with 'shots' and other impurities
- Detecting and removing duplicate fibers from tracking results.

Lastly, the effect of the impurities, as well as the size of the sample and number of fibers tracked, should also be investigated further.

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