Advanced Visualization Methods for Porosity in Carbon Fiber Reinforced Polymers

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Abstract

This work presents advanced methods for the characterization and visualization of porosity in carbon fiber reinforced polymers (CFRP). The developed visualization pipeline for the interactive exploration and visual analysis of CFRP specimens enhances the evaluation workflow for non-destructive testing (NDT) practitioners. Besides the calculation of local pore properties, i.e., volume, surface, dimensions and shape factors, we show novel visualization approaches to explore pores in a CFRP specimen. We introduce Porosity Maps (PM), to allow for a fast porosity overview showing areas with high and low porosity in the specimen. Pores are filtered with parallel coordinates according to their local properties. Furthermore a histogram-based best-viewpoint widget is introduced to evaluate and visualize the quality of viewpoints on a sphere.

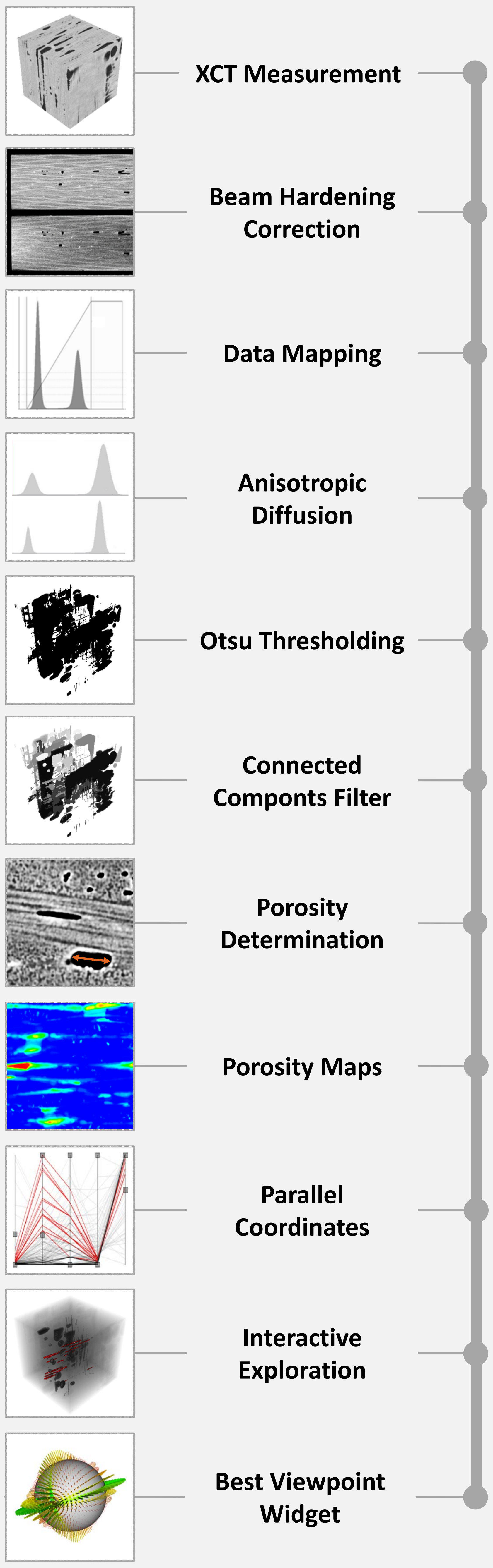
Motivation

The demanding requirements in industrial research lead to an extensive effort in designing new, tailored and lightweight materials. Especially in the aeronautics industry there is a high demand for advanced composite materials, e.g., carbon fiber reinforced polymers (CFRPs), due to their increased stiffness and strength-to-weight ratio. As a result of manufacturing artifacts this material tends to have pores inside. Pores have a large impact on the mechanical properties of a specimen such as compressive and interlaminar shear strength as well as the elasticity modulus of the material. It is an important task in quality control to quantify and study the porosity of such materials. Besides quantitative porosity, the distribution and shape factors of pores are important properties for CFRP analysis. In this work, we introduce a visualization pipeline that is customized for the interactive exploration and visual analysis of pores in CFRP specimens.

Data Acquisition

In this work, we used samples of pre-impregnated fibers (PrePreg) consisting of carbon fibers and 40 weight percent epoxy resin. By varying the vacuum pressure during the heating phase, plates with a porosity between 0 % and 10 % were manufactured. For the porosity determination and visualization, 6 specimens were cut out of these plates. They are denoted as PrePreg 1-3 with a size of 17 x 20 x 4.5 mm^3 each and PrePreg 4-6 with a size of 17 x 20 x 2 mm^3 each. The resulting voxel size of our measurements is 10 µm. All XCT scans were performed on a GE Phoenix|xray nanotom XCT system with a 180 kV nano focus tube. The measurement was performed with a tube voltage of 60 kV and varying projections between 1500 and 1800. The reconstruction algorithm of the device included a correction for beam hardening which avoids over-segmentation in the middle of the specimen due to gray value modifications caused by the beam hardening effect during the measurement.

Visualization Pipeline



XCT Measurement

Beam Hardening Correction

Data Mapping

Anisotropic Diffusion

Otsu Thresholding

Connected Componts Filter

Porosity Determination

Porosity Maps

Parallel Coordinates

Interactive Exploration

Best Viewpoint Widget

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Porosity Maps Visualization

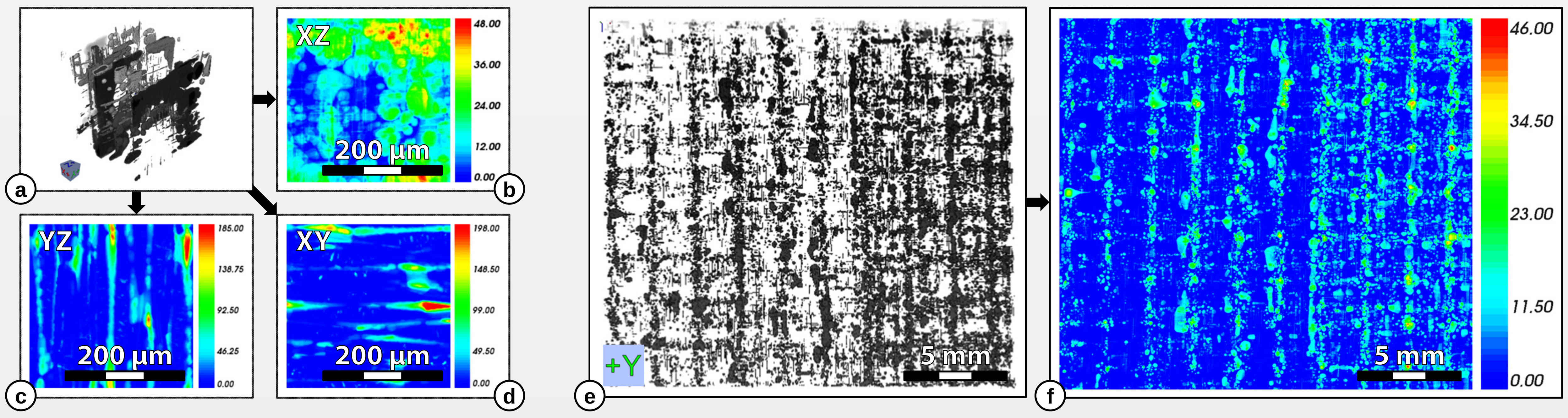

Figure 1: A porosity map (PM) shows areas with high and low porosity. We calculate PMs for the three axis-aligned directions (b, c and d) of a XCT dataset (a). To calculate an individual pixel of a PM, all pore voxels along a ray in slice direction are summed up. Finally the PM values are mapped to colors. To ensure comparability to other reference methods of the domain experts we use rainbow color maps. The rendering (e) shows the segmented pores of a CFRP specimen and its corresponding PM (f). The PM visualizes the pore homogeneity and areas with low (blue) and high (red) porosity. Aligned pores in the dataset will produce high, hollow peaks in the PM, whereas a jittered arrangement of the pores will lead to lower but wider peaks.

Interactive Exploration of Pores

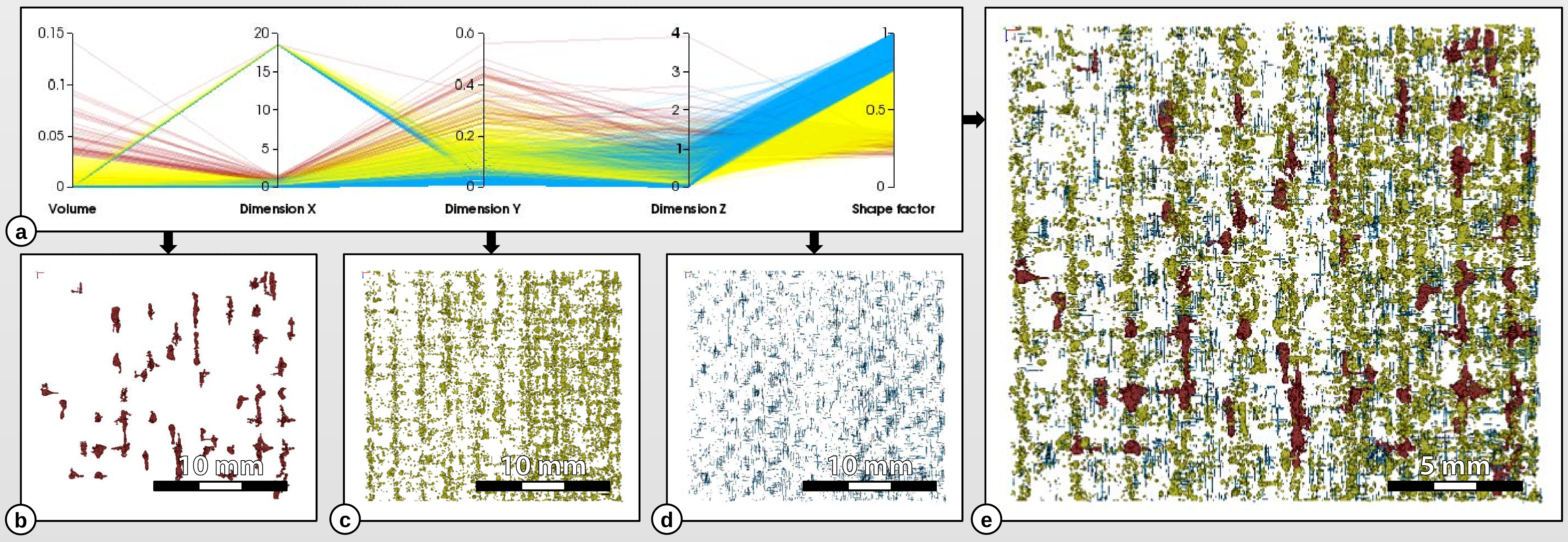

Figure 2: Visualization showing the interactive exploration of individual pores. Using the parallel coordinates visualization (a) three classifications of pores are highlighted. Big pores are shown in red (b). Smaller nodular and disc-shaped pores are highlighted in yellow (c). Blue indicates the long and thin micro pores in the fiber bundles (d). For further filtering of the long and thin micro pores in a specific direction, e.g. x or z direction according to the twin-weave fiber pattern, the dimension bounds can be set in the parallel-coordinates view additionally to the shape factor. All these classifications can be combined in one visualization (e).

Best-Viewpoint Visualization

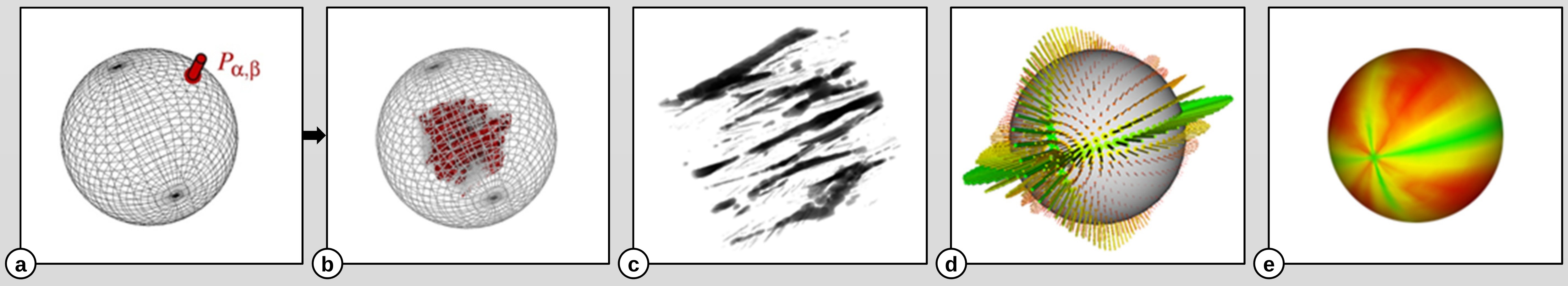

Figure 3: The goal of the best-viewpoint calculation is to evaluate the quality of viewpoints. In the domain of CFRP characterization, a good viewpoint maximizes the pore overlap in the result image so that the fiber structure is better visible. The opacity of the pores is adjusted in relation to the maximum length of the volume. Overlapping pores cause darker areas in the image. All possible viewpoints are given as a parameterized sphere surrounding the specimen (a). The direction for the PM calculation is then defined by connecting the viewpoint on the sphere to the sphere center (b). We calculate PMs for all viewpoints on the sphere and evaluate them by calculating a quality value for each viewpoint. The rendering in (c) depicts a good viewpoint. We encode the quality of the viewpoint on a sphere. (d and e) show our proposed methods for the best-viewpoint visualization. (d) Our first approach shows a gray sphere with colored cylindrical sticks whose lengths correspond to the calculated quality values. (e) In our second visualization method viewpoints are color mapped on a sphere. Good viewpoints are shown in green. Red indicates an unfavorable viewpoint. In our implementation the rotation of the viewing sphere is linked to the corresponding rotation of the specimen.

[1] A. Reh, B. Plank, J. Kastner, E. Gröller and C. Heinzl. Porosity Maps - Interactive Exploration and Visual Analysis of Porosity in Carbon Fiber Reinforced Polymers. Computer Graphics Forum, 31(3):1185-1194, June 2012.

Research and Development

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