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3D IMAGE SEGMENTATION AND CYLINDER RECOGNITION FOR COMPOSITE MATERIALS

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Abstract

The modelling of three-dimensional composite carbon fibers-resin materials for a multi-scale use requires the knowledge of the carbon fibers localization and orientation. We propose here a mathematical method exploiting tomographic data to determine carbon localization with a Markov Random Field (MRF) segmentation, identify carbon straight cylinders, and accurately determine fibers orientation.

Introduction

X-ray computed tomography is a powerful non-destructive technique allowing to see inside an object without destroying it. This method uses a series of two-dimensional radiographic images rotated around an axis of rotation to get a three-dimensional image of the object with reconstruction algorithms. In particular, this technique can be used to obtain three-dimensional views of composite materials to study their structure and properties.

<u>Problem and Purpose</u>

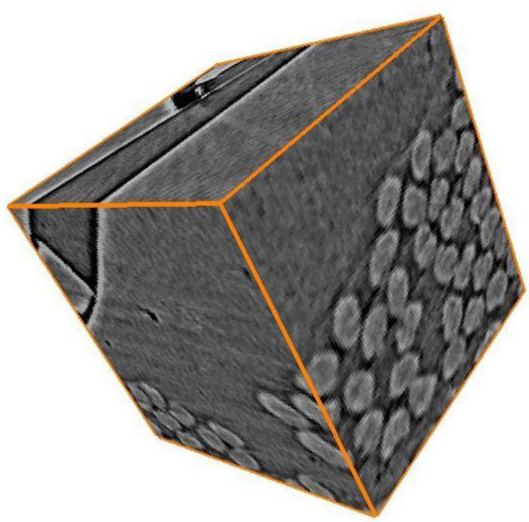

Figure 1. 3D rendering (ESRF synchrotron, voxel size: 0.7µm) of a fibers-resin composite X-tomography. Light-gray areas are carbon fibers (and a pore), and dark areas are resin.

In order to model macroscopic structures of composite materials with small characteristic dimensions, it is necessary to replace them by homogeneous materials with similar properties.

This allows to describe structures by fewer variables and leads to fast computation codes. We consider the case of a carbon fiber-resin composite (Figure 1.) and look for a well-scaled thermal equivalent homogeneous material. For that purpose, two different datasets are required namely properties of each component (experimentally measured) and their repartition (localization and orientation) in composite material. To get relevant structures of composite material, we use 3D X-tomographic images. However, the segmentation process for each component is not straightforward (as shown on Figure 3.).

Chosen Approach

We present here processing methods to obtain segmented images that we use next to search the orientation of carbon fibers. We use a homemade Markov Random Field (MRF) software [1,3] to perform segmentation with a global fitting data term and a local interaction term as well. We first use the Potts model [4] with and without parameter optimization. These methods have the advantage to be easily computable and parallelizable, with linear complexity, and provide good results.

The considered material is a carbon fiber/phenolic resin composite, whose fibers can be approximated by cylinders. Fibers are spatially connected in *yarns*, composed of fibers with the same orientation and separated by a resin zone. Yarns form a non-dense weaving into resin matrix.

We propose a method for lines recognition which consist in considering a closed surface section and gathering cylindrical sections comparing pixels between them with a component-connected labelling algorithm [2]. Finally, a method for reconstitute yarns is proposed with a K-means clustering algorithm [8] and a Delaunay triangulation [9,10].

Image Segmentation using Markov Random Fields

Markov Random Fields Model

Images spatial properties may be considered from global and local points of view. MRFs give a convenient way to model local informations such as pixels grey level and/or correlation between them. For that, MRF distributions are used to quantify contextual informations in images.

Let $\mathcal{L} = \{0,1\}$ be the considered label set for our problem, and $\mathcal{D}$ the set of voxels values for our image. Let $\boldsymbol{X} = (X_i)_{i\in S}$ be a family of random variables indexed by S, every variable X_i taking its value x_i in $\mathcal{D}$. Such a family $\boldsymbol{x} = (x_i)_{i\in S}$ is called a random field and is a configuration of $\boldsymbol{X}$. We similarly define $\boldsymbol{Y} = (Y_i)_{i\in S}$ with values in $\mathcal{L}$. Moreover, we consider a neighborhood system $\mathcal{N}: i \in S \to \mathcal{N}(i) \in \mathcal{P}(S)$ the power set of S, and we define a **clique** as a subset of sites for which every pair are neighbors. We assume that $\boldsymbol{Y}$ is a MRF if it satisfies:

- Positivity: $\forall \boldsymbol{y}, \mathbb{P}(\boldsymbol{Y} = \boldsymbol{y}) > 0$.
- Markovian condition: $\mathbb{P}\left(Y_s = y \middle| \boldsymbol{Y}_{S\backslash s} = \boldsymbol{y}_{S\backslash s}\right) = \mathbb{P}\left(Y_s = y \middle| \boldsymbol{Y}_{\mathcal{N}(s)} = \boldsymbol{y}_{\mathcal{N}(s)}\right)$ [3,5].

The Markov field associated probability density function is a Gibbs distribution according to Hammersley-Clifford theorem [1]. Thus

$$\mathbb{P}(\boldsymbol{Y} = \boldsymbol{y}|\boldsymbol{X} = \boldsymbol{x}) = \frac{e^{-U(\boldsymbol{y}|\boldsymbol{x})}}{Z(\boldsymbol{x})}$$