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Robust 3D segmentation of composite materials fibres

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1. Introduction

Novel composite materials manufacturers need to characterise the materials they produce. This implies subjecting their production to a battery of various physical tests, under various conditions of temperature, pressure, atmosphere, etc. Such test are typically expensive in both money and time, driving a need for materials macroscopic modeling based on microscopic characteristics. In this context, recent developments in imaging processes such as X-ray micro-tomography have enabled the production of 3D images of materials micro-geometries at unrivalled resolutions. Accordingly, increasing levels of details linked to improved analysis capabilities are leading an improvement in properties estimations.

Materials containing fibres are used increasingly for their interesting physical properties. To characterise such materials, a productive start is to consider the fibres directions and intersections. This requires a segmentation of the fibres, which are embedded in a resin matrix.

In this paper, using a set of two 3D high quality micro-tomography images as example, we propose a robust segmentation method. This method combines a morphological approach with geometric parameter estimation.

2. Segmentation process

The segmentation process that we developed consists of four operations that have to be executed sequentially. The methods used to estimate the parameters are also discussed.

2.1 Area closing and opening

The first transformation applied to the original images are an area closing followed by an area opening. An area closing (resp. opening) [6] is in fact an instersection (resp. union) of morphological closings (resp. openings) with a structuring element depending on a parameter λ_1: $\gamma_{\lambda_1} = \bigvee_i \{\gamma_{B_i} / B_i$ is connected and $\mathrm{card}(B_i) = \lambda_1\}$ where B_i is a structuring element. λ_1 is the size (e.g. expressed in number of pixels) of the structuring element. This first operation operates a smoothing on the image, filtering the high peaks and troughs with small spatial extention, due to noise or irrelevant image objects due to the high-resolution nature of the input data. This operation is required for the rest of the segmentation; experiments showed that the value of λ_1 is not critical within at least two orders of magnitude between 10 and 1000, but it is required to be greater than zero. Tests performed with this step omited resulted in a poorer outcome.

2.2 Morphological opening by an Euclidean ball

The aim of the automation of this part of the segmentation process is to determine the radius of the ball used for the opening. Euclidean balls were chosen as structuring elements because the fibres are close to cylindrical with circular cross-section. Initial manual tuning revealed that the radius of the optimal opening ball was half the radius of the fibres. Therefore we need an approximate value for the fibres average radius.

A study of a granulometry by opening of the available samples was performed. The curves obtained are decreasing sharply when the opening radius becomes greater than the fibres radius. This is clearly due to the disappearance of the corresponding fibers, caused by an opening that absorbs them in the background. Figure 1 shows an example of the first derivative of the granulometric curve.

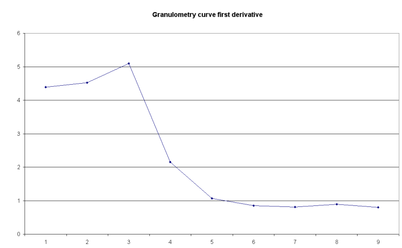

Figure 1. An instance of the derivative of the granulometry curve. This curve exhibits a sharp drop between 3 and 4, which corresponds to half the mean radius of the fibers.

The granulometric curves allows us to determine an averaged radius for the fibres, and as a consequence a value for the opening ball.

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2.3 Second area opening

The opening of the previous section is not strong enough to eliminate all the composite matrix elements. There are non-fibres elements that are still visible in the image after the previous step, preventing an easy thresholding. To delete these, we used another area opening, for which the parameters can be dynamically computed as follows:

Assuming the image data is contained in a cube of edge length a, we want to keep all the fibres that intersect the inner centred cube of edge length of $\frac{a}{2}$. The fibres that does not go through it are considered to be too small, they can be deleted without too much loss of information. Considering the volume of the shortest fibre tangent to one of the edges of the inner cube lead us to compute the opening parameter: $\lambda_2 = \frac{\pi d^2 a}{2\sqrt{(2)}}$.

2.4 Final threshold

The previous operations results in an image whose histogram is readily interpretable. It exhibits a plateau of constant small value, in between two peaks representing respectively the fibres and the background.

3. Results and discussion

This method was used on two independent sets of 63 images of size 256^3 derived each from one different acquired cube of data of dimension 2048 pixels in each direction and was observed to produce good experimental segmentations results with a 0% error rate in the number of fibres.

The segmentation method outlined in this abstract depends on few parameters, all of which can be estimated from the image content and its geometry. Figure 2 is a 3D visualisation of a subset of the original data segmented with the described method.

4. Future work

The method described in this paper provides good fibre localisation results, however it provices only an approximation of the surface of the fibres. An accurate fibre surface detection is necessary for some downstream studies, such as fibre damage assessment before/after material casting.

To improve on the accuracy of the fibre border detection, a second pass can be performed, using for instance watershed [2] or interchangeably continuous maximal flows [1].

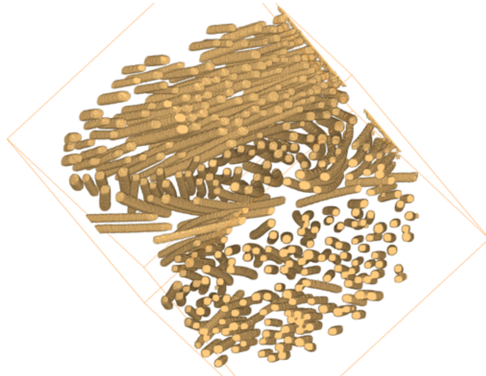

Figure 2. 3D visualisation of the segmentation method result.

We are also interested in a graph of the distribution of the fibre directions. To achieve that, several approaches are being investigated :

First, morphological openings by linear elements can be used to yield a rose of direction [5]. However, this idea needs to be extended to 3D, using the Euler angles θ and ϕ as parameters and the volume remaining after the opening as the functional characteristic. This solution would ideally require an isotropic segment direction distribution, a problem that is classically known not to have a general solution in 3D [3]. However, approximate solutions to this problem can be devised [4]. Another method currently under study consists of using the directional information derived from the distance map in the fibres.

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