RESTORATION OF TEXTILE YARN DISTORTED LOW-RESOLUTION MICRO COMPUTED TOMOGRAPHY CROSS SECTION IMAGES: A MATLAB RESTORATION ALGORITHM

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https://doi.org/10.37904/nanocon.2023.4809

Abstract

Textile yarn is a group of twisted fibers with diameters of a few micrometers, requiring a nano-resolution scanner to capture precise details of the single fibers perfectly to make a digital twine of the scanned yarn. Computed tomography (CT) technology can 3D digitally scan the sample and achieve a digital twin. The fine fibers' diameter requires a nano-CT to achieve a high-resolution yarn's digital twin; nano-CTs are more expensive than micro-CTs and require about eight times the scanning time compared to micro-CTs, which means more computational power to reconstruct and analyze the scanned objects. This paper introduces a systematic MATLAB algorithm to regenerate distorted yarn's micro-CT low-resolution cross-section images. The algorithm segments the distorted images' fibers, identifies them, and regenerates the clean, high-resolution fibers. The algorithm performance is compared to the optical microscopic cross-section image measurements using ImageJ. The results revealed that before processing, the mean fiber diameter measured 9.60 ± 0.78 μm, while post-processing it measured 10.33 ± 0.49 μm. Notably, the algorithm effectively decreased the dispersion of fiber diameters around the mean by 40%, maintaining a diameter close to the design diameter of the fibers of 10 μm.

Keywords: Yarn, fibers, micro-computed tomography, cross-section images, MATLAB, algorithms, ImageJ.

1. INTRODUCTION

For years, the textile industry has employed various imaging technologies for quality control, inspection purposes, and defects detection [1]–[3]. These defects can be automatically detected using image processing and computer vision algorithms, ensuring that only high-quality materials are used in the production process and improving the overall quality of the final product.

In textile engineering, it is crucial to visualize the internal structure of textile materials as it enables manufacturers to identify defects and irregularities that may not be visible on the surface alone and to validate the production parameters. One recent technology that has gained considerable attention is micro-computed tomography (micro-CT). Micro-CT is a non-destructive imaging technique that generates detailed cross-sectional images of scanned objects and materials, providing a 3D view of their internal and external structure [4]. Micro-CT can produce images with resolutions as fine as a fraction of a micrometer [5], enabling the detection of the tiniest defects. Furthermore, the 3D nature of micro-CT images allows the creation of accurate digital models of the material, which can be analyzed using image processing and computer vision algorithms.

By combining micro-CT with image processing and computer vision technologies, new avenues have opened up for textile engineering, particularly in defect detection [6], fiber analysis [7], and material characterization [8]. Moreover, micro-CT provides digital twins of the scanned objects, enabling the usage of these 3D digital twins in modeling and simulation studies [9], [10].

Textile yarn is a group of twisted fibers with diameters of a few micrometers, requiring a nano-resolution scanner to capture precise details of the single fibers perfectly. Nano-CTs are more expensive than micro-CTs and require about eight times the scanning time compared to micro-CTs [11], which means more computational power, time, and data to reconstruct and analyze the scanned objects. The cross-sectional imaging of textile yarns is crucial to understanding yarn structure and behavior. Several methods exist to obtain such images, including microtome sectioning, micro-computed tomography (micro-CT), and epoxy grinding/polishing [12]. Shinohara proposed clustering voxels based on their distance to the yarn center point [13] and used Mahalanobis distance, which also considered fiber distribution [14].

To solve this problem, this paper introduces a systematic MATLAB algorithm to enhance distorted yarn's micro-CT low-resolution cross-section images. The algorithm segments the distorted images' fibers, identifies them, and regenerates the clean, high-resolution fibers. The algorithm performance was compared to the optical microscopic cross-section image measurements in terms of homogeneity and fibers shape and to the unprocessed micro CT cross-section image in terms of fibers' diameters using ImageJ [15].

2. MATERIALS AND METHODS

A polyester yarn sample (1.4 dtex/38 mm), with the following parameters: yarn count: 34 Nm, twist coefficient (α): 110, fiber diameter ≈ 10 μm, and twist level: 650 Z/m, was scanned using Bruker Skyscan 1272 (Bruker, Billerica, MA, USA) Micro-CT machine according to the scanning protocol and parameters in a previously published article by our group [12]. **Figure 1** shows the textile yarn cross-section images obtained using the Bruker Skyscan 1272.

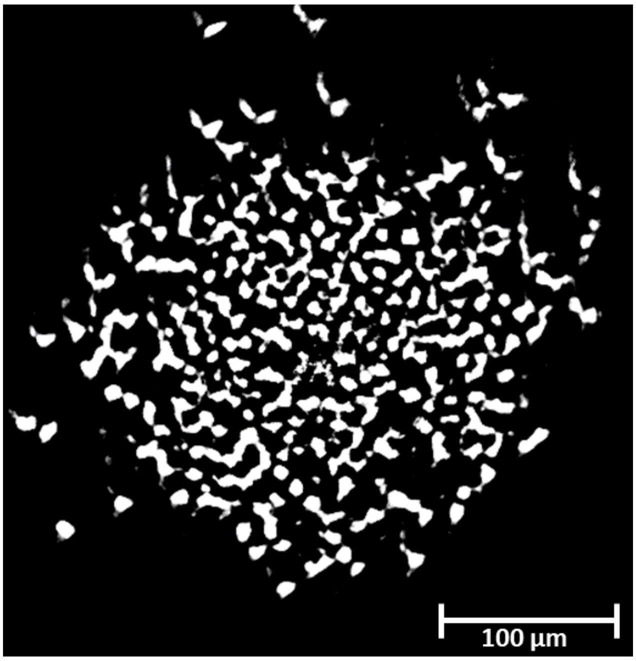

Figure 1 Cross-section image of the Polyester textile yarn scanned by Bruker 1272 micro-CT scanner

The proposed algorithm processes the cross-section images in two steps: first, it finds the diameter of each fiber of the distorted/low-resolution cross-section image and then regenerates the high-resolution circular fibers. The algorithm consists of two steps/two files; the first step is to allocate and measure the diameter of the low-resolution distorted fibers in the cross-section image. The second step creates a new cross-section image with clear and high-resolution fibers using the information extracted in the first step (the location and diameter of each fiber in the original cross-section image). **Figure 2** shows the algorithm working scheme in two phases.

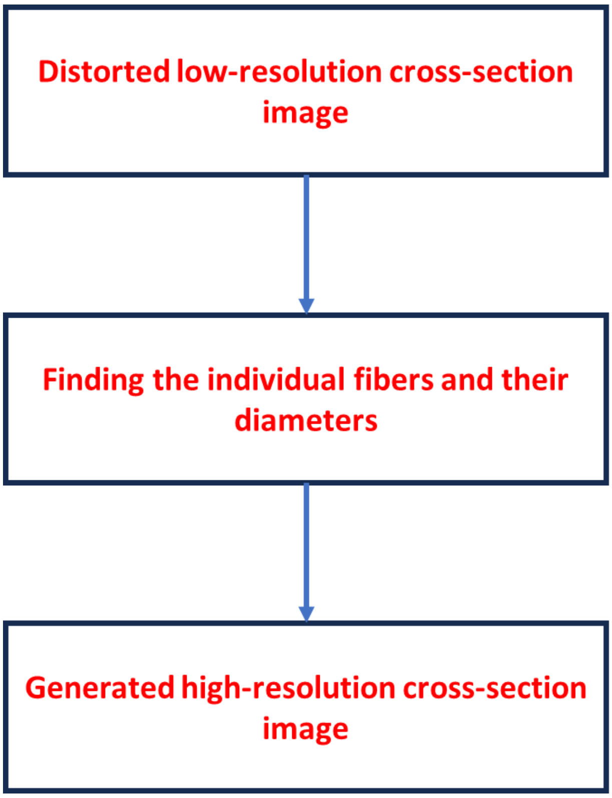

Figure 2 Cross-section images algorithm working scheme

The algorithm consists of two codes written in MATLAB scripting language. The codes can be downloaded from GitHub [16], where the MATLAB files, algorithms description, and their illustrations. There are two code files: The yarn diameter and the regen cross-section.

Figure 3 shows the processed cross-section image from **Figure 2** after being processed by the yarn diameter MATLAB code.

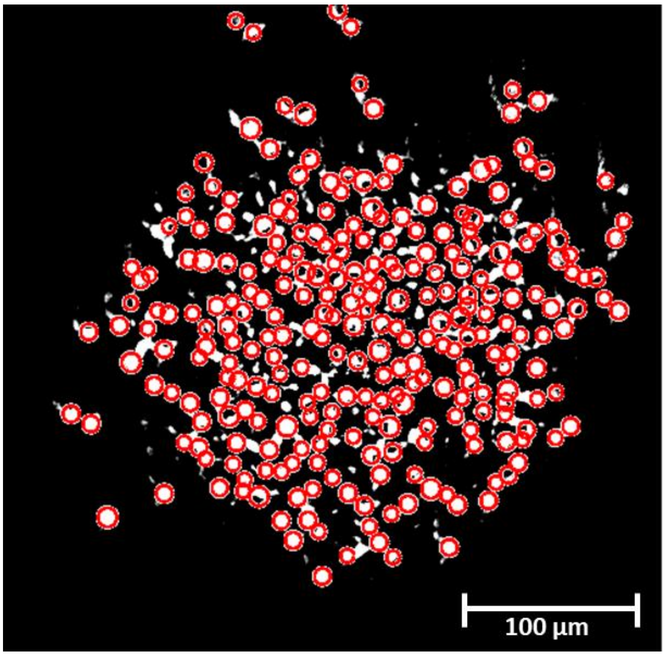

Figure 3 The detected fibers in the yarn’s cross-section and their circular diameters

Figure 4 shows the generated cross-section image with circular, high-resolution individual fibers using the location and diameter as shown in red in **Figure 3**. The image is generated by the regen cross-section MATLAB code and compares it to the cross-section optical microscope image obtained by the epoxy grinding-polishing method as reported in our previous article [12]. It's noticed that the homogeneity of both images are quite similar, unlike the original cross-section images produced by the micro CT machine.

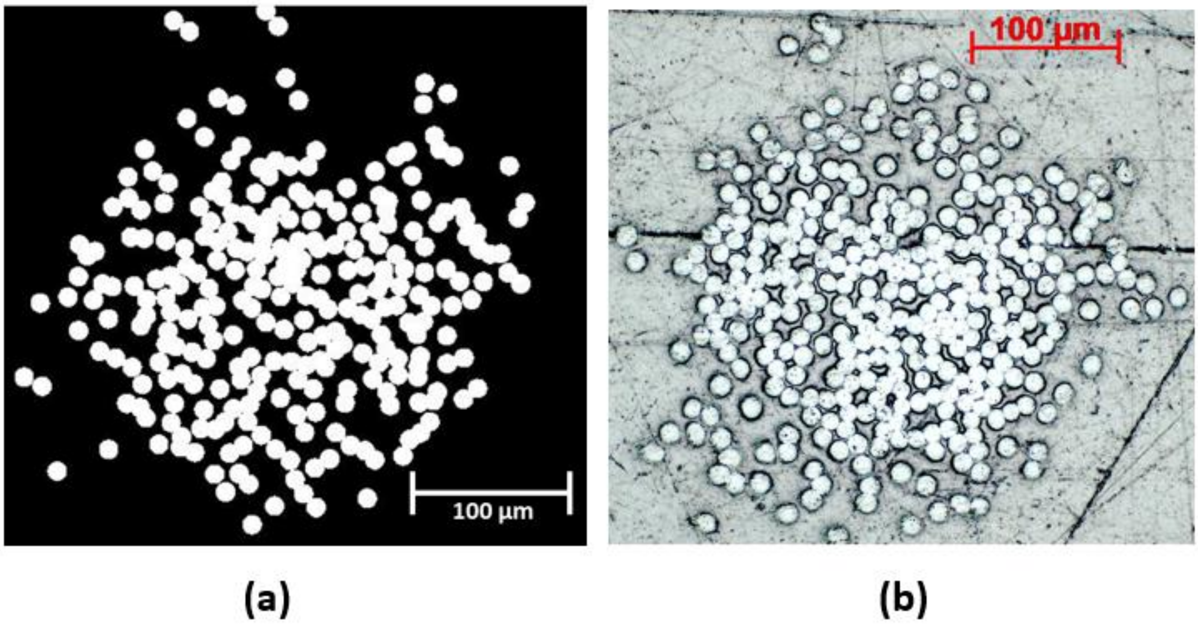

Figure 4 (a)The regenerated cross-section image using the proposed algorithm, (b)The cross-section optical microscopic image of the same yarn.

ImageJ software was used to measure the fiber diameters in the cross-section image that was generated from the micro-CT machine and the one that was created using the algorithm, thirty diameter measurements were collected for the cross section before and after applying the algorithm on the cross-section image. **Figure 5** shows the histogram of the fiber's diameters measurements before and after being processed.

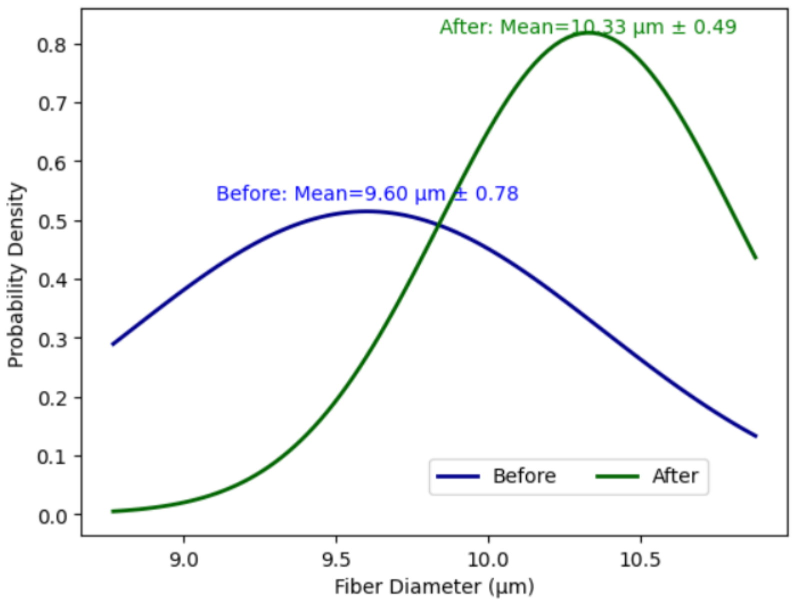

Figure 5 Fibers' diameters distribution before and after being proceeded by the proposed algorithm.

3. CONCLUSION

The paper introduces a MATLAB algorithm that consists of two codes. The first codes process the cross-section images of a polyester yarn scanned by Skyscan 1272 micro-CT scanner and extract the circular fibers' locations and their diameters. The second code recreates the cross-section image using the information extracted using the first code, producing a high-resolution image with clear and homogeneous fibers that could be compared with optical microscope images. the results showed that before the processing the average fiber's diameter was 9.60 ± 0.78 µm and after the processing was 10.33 ± 0.49 µm. It's noticed that the algorithm reduced the fibers' diameters dispersion around the mean value by 40% and the obtained diameter is still around 10 µm, which is the actual design diameter of the yarn's fibers.

The proposed algorithm is promising to enhance and restore the textile yarn micro-CT scans, which would produce a 3D digital twin that mimics the actual yarn's structure without the need to use a nano CT. Thus, saving time, data, and computing power.

ACKNOWLEDGEMENTS

This work was supported by the project no. TK03020219: Sensor Materials and Systems for Distributed Condition Monitoring of Energy Cables" (Technological Agency of the Czech Republic, program THETA)

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