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Estimation of spatial distribution and symmetry of textile materials using numerical classification

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ABSTRACT

Numerical classification of textile materials, here aramid, viscose, and PAN/WV, is proposed using lacunarity analysis of monochromatic digital representations of optical microscopic images. The method is sensitive to the spatial distribution of fibers and, equivalently, to the empty spaces between them. This means that lacunarity is able to quantitatively express a given level of spatial in-plane symmetries of single-face fabrics.

1 Introduction

Structural analysis using image processing approaches is an important tool for quantitative characterization of textile materials, i.e., regularity, periodicity, yarns quality and fibers structure symmetry. Such testing methods can be implemented in computer programs based on different mathematical algorithms, such as simple pixel counting, random walks on digital photographs [1], fractal dimension calculations [2,3], and other less known characteristics such as succolarity [4] and lacunarity [5,6]. Statistical analysis of images and/or structural samples can be carried out by many different methods, like for example, diffusion with hopping [7-9] and deterministic chaos [10-11].

While fractal dimension measures self-similarity of patterns and is directly related to the material structure or its spatial regularity, the lacunarity senses additionally empty spaces between areas filled with material and correspondingly the associated material spatial distribution. However, what is especially important for the analysis presented here, the properly calculated lacunarity parameter is insensitive to spatial directional properties – i. e. isotropy vs. anisotropy – what can be tested by analysis of rotated photographs of samples. We explain the reasons for that property in the next section.

In this paper we report first results of lacunarity calculations for three textile samples weft-knitted from aramid, viscose, and polyacrylonitrile (PAN)/wool, providing a quantitative estimation of the materials' spatial distribution and the spatial in-plane symmetry of single-jersey fabrics [6]. Before, we shortly introduce the notion of lacunarity, and finally provide some conclusions.

2 Notion of lacunarity

Calculation of lacunarity is based on repeated pixel counting performed on monochromatic photographs. A picture under investigation is covered with squares of a defined side length a (Fig. 1). Firstly, a square is drawn in the upper left position, then it is moved horizontally step by step, from left to right, with a step width smaller than or equal to the square side length, for example half of it, followed by the next row, etc. [12]. The overlap of boxes is the same in horizontal and vertical directions.

The number of material (black) pixels, here representing textile material, is counted at each square position – the obtained result is called a box-mass. Next, the squares and box-masses are classified in the form of a probability distribution $P(a, p)$. The distribution tells us how many squares $N_p(a)$ of side length a contain p black pixels, thus $P(a, p) = N_p(a)/N(a)$, where $N(a)$ is total number of squares covering the whole image. The experiment is repeated for a wide range of side lengths a, usually ranging from 0.1 to 1.0 of one of the photograph edge lengths.

For the obtained probability distribution, we can calculate two quantities: the weighted average value of box-masses $\sum_p p \cdot P(a, p)$, and the weighted average of squared box-masses $\sum_p p^2 \cdot P(a, p)$. Finally, the lacunarity is defined as

$$L(a) = \sum_p p^2 \cdot P(a, p) / \left(\sum_p p \cdot P(a, p)\right)^2. \quad (1)$$

This quantity is proportional to the ratio of the standard deviation of the probability distribution to the mean value of the box-mass. In other words, it measures the ratio of the uncertainty of spatial material distribution – in this way it is sensitive to empty space regions located between material-covered areas – to the mean value of material distribution in single face fabrics. Since the procedure is repeated for a range of covering box sizes, it is then possible to prepare the $L = L(a)$ dependence, usually in the form of a double-logarithmic figure.

An especially important property of the proposed method is its insensitivity to the image orientation. Thus, the comparative test can be carried out with a given image orientation and with an image rotated in-plane by 90 degrees. Such a procedure enables finding the parameter of lacunarity which characterizes textile patterns. In the next paragraph we present results of both lacunarity and special tests with rotated samples.

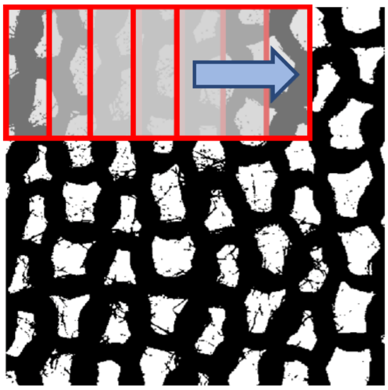

Fig. 1 Graphical presentation of the local collection of the material pixel density using horizontally moved square regions. The number of black pixels collected at a given position represents the box-mass for the corresponding position.

3 Samples

Single face fabrics were produced on a flat knitting machine CMS 302TC by Stoll, gauge E8, using the following yarns: aramid (550 dtex), viscose (2 x 330 dtex), and blended fibers with 70 % polyacrylonitrile (PAN) and 30 % new wool (WV). Photographic images were captured using the digital optical microscope VHX-600D (Keyence) and a nominal magnification of 20 x. The pictures, before calculations, were then transformed into 1-bit, monochromatic maps in the png format using arbitrary free graphics software. Each analyzed region has the size of 5000 x 5000 pixels. Fig. 2 presents samples in the original orientation (left panels) as well as in the 90° rotated form (right panels).

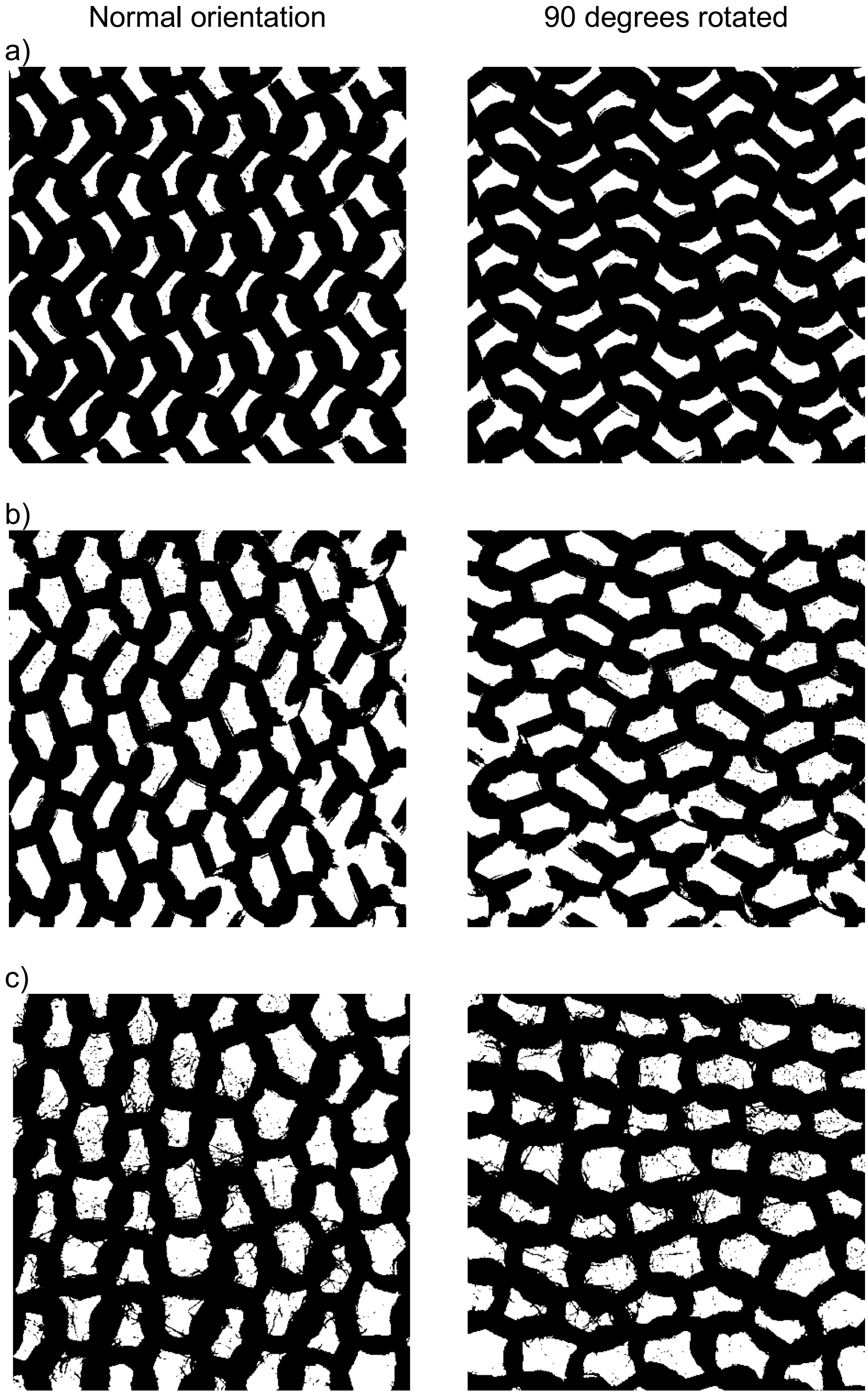

Fig. 2. Three types of samples in original orientation (left panel) and 90° rotated orientation (right panel): (a) aramid, (b) viscose, and (c) PAN/WV.

4 Results of Calculations

The visual inspection of the photographs in Fig. 2 might provide some intuitive estimation of the spatial distribution and symmetry of fibers. This is, however, a very inadequate approach of rather weak technological importance.

In Fig. 3, the calculated lacunarity, for the original images, is depicted for different sensing squares as defined above, providing an unambiguous method of dividing the analyzed structures into two classes: aramid and viscose belongs to the same group of lower lacunarity, while the PAN/WV is unequivocally different. In other words, a lower lacunarity is clearly visible in the range of $\mathrm{a} > 800$, meaning denser material with less empty regions. It should be mentioned, however, that the slopes of all curves are “concave down”, as typical for images with high lacunarity [13,14], due to the large open pores between the yarns in all cases.

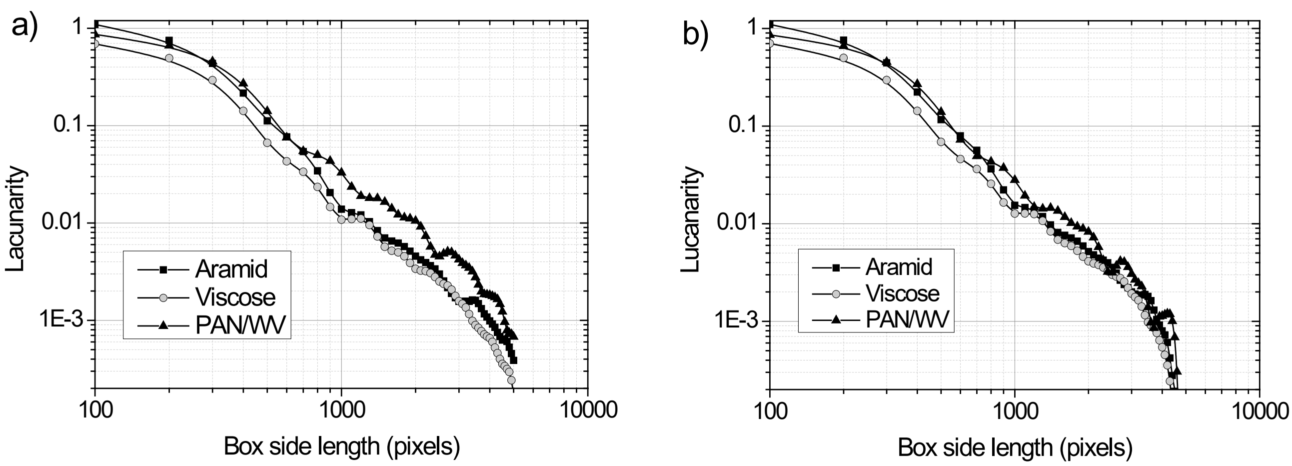

Fig. 3. Lacunarity of investigated samples as a function of the moving square-side length a for nonoverlapping testing boxes (a), and for 50 % overlapping boxes (b). The maximum value of a equals 5000, i.e. the length of the analyzed photographs.

Rotation symmetry analysis proves quantitative results which cannot be directly checked by the human eye (Fig. 4). The lacunarity is calculated as the absolute, stable average value of normal and rotated positions. From the linear scale point of view, for $\mathrm{a} < 750$, the results are numerically unstable, providing some inside into the nature of the pattern; however, with relatively small deviations between both rotational directions (< 1 %) which can in most practical cases be ignored.

For the presented samples, lacunarity can be read out with an even higher accuracy above a threshold value of $a > 750$. Thus for example, for $a = 800$ the lacunarity read out from Fig. 3a equals 0.034 for aramid, 0.024 for viscose, and 0.050 for PAN/WV, i.e. values differing significantly more than the maximum deviations visible in Fig. 4.

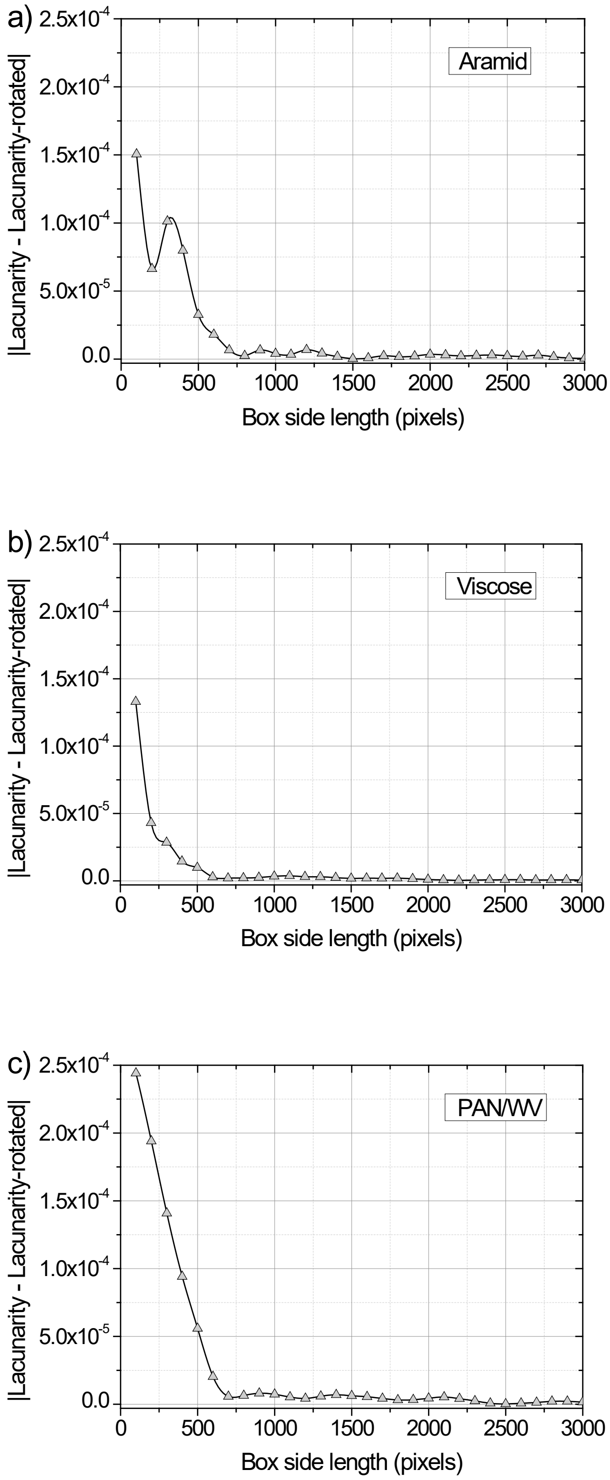

Fig. 4. Lacunarity of tested materials as a function of the moving square side-length a with a linear scale. The maximum value of a equals 5000, i. e. the edge length of the analyzed photographs: (a) aramid, (b) viscose, and (c) PAN/WV.

5 Conclusions

Lacunarity analysis, less commonly known as a tool for textile material characterization – in comparison to standardized methods – appears to be a very useful tool for the quantitative classification of the spatial symmetry and the degree of material filling of textiles, while it is angle-independent within the accuracy of numerical treatment. This new classification method should support the existing tests. Comparing three different materials, we were able to classify their regularity and their cover factors. The quantitative analysis performed with aramid, viscose and PAN/WV revealed that the latter exhibited the highest value of lacunarity.

Future research efforts will try to correlate this type of analysis with other physical parameters and technological methods used in the textile industry. Also, the aim of authors is to elaborate a lacunarity database for a wide range of textile samples and offer in this way a new adequate method of quantitative classification.

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