HOUGH TRANSFORM BASED AUTOMATIC SEGMENTATION OF NANOFIBERS FROM SEM IMAGES

Z. Hu[1], B. Tseng[2], Y. Lin[3], J. Wu[2*],
[1] Department of Electrical and Computer Engineering, University of Texas at El Paso, El Paso, TX 79968, USA
[2] Department of Industrial, Manufacturing and System Engineering, University of Texas at El Paso, El Paso, TX 79968, USA

[3] Department of Mechanical Engineering, University of Texas at El Paso, El Paso, TX 79968
*Corresponding author (jwu2@utep.edu)

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ABSTRACT

In this paper, a partitioning Hough transform method is proposed to automatically extract nanofibers from SEM images for nanocomposites morphology analysis. This method first divides the image into partitions with connected fibers and then apply the Hough transform to the skeleton of each partition to avoid the influence of other partitions. Compared with the standard Hough transform, this method is much more robust and has higher segmentation accuracy.

1 Introduction

Nanofibers have been widely used as reinforcement to form various nanocomposites with significantly enhanced mechanical and other functional properties [1, 2]. The morphology (e.g., spatial distribution, fiber orientation) of nanofibers in the base material plays a critical role in determining the enhancement of material properties. In structural applications, uniform distribution of nanofibers in terms of both spatial location and orientation is desirable to achieve the best mechanical properties. However, in some other applications, alignment of nanofibers with the same orientation is more preferable. For example, in the dielectric nanocomposites manufacturing used in high performance capacitors, well-aligned nanofibers could increase both permittivity and breakdown strength, and thus increase the energy density of capacitors [3].

Currently, the standard quality inspection technique is morphology analysis of nanofibers imbeded in the base material based on microscopic images, e.g., scanning electron microscope (SEM) images. The morphology analysis is often based on visual inspection of SEM images, which is subjective and lack of quantitative measurement of distribution quality of nanofibers. This paper develops a novel image segmentation method, i.e., partitioning Hough transform method, to automatically identify both the location and orientation of nanofibers for further morphology analysis. The rest of the paper is organized as follows. Section 2 will present the methodology. The case study and results will be given in Section 3.

2 Methodology

2.1 Introduction of Hough Transform

Hough transform was invented by Richard Duda and Peter Hart in 1972, named as "generalized Hough transform" since the 1962 patent of Paul Hough. It is an important segmentation method to detect edge or a certain class of shapes by voting procedure. The classic Hough transform was used to detect straight lines in the image, and then it extend to arbitrary shapes like circle and ellipse.

The basic idea of Hough transform is to transfer a point from the physical domain to a curve in its parameters' domain. A line in x-y plane can be uniquely defined by its distance r from the origin and the orientation angle θ as $cos\,\theta + y\,sin\,\theta = r$, as shown in Fig. 1 Therefore, this parameterization maps every line in x-y plane to a point (θ, r) in $\theta - r$ domain. For a point P_0 (x_0, y_0), all lines passing through it could be expressed as $x_0\,cos\,\theta + y_0\,sin\,\theta = r$ where r is the distance from the origin to the line, and θ is the angle. Therefore, the point P_0 is mapped from (x_0, y_0) to a curve in the $\theta - r$ domain. Based on this transform, for points lying on the same line in x-y plane, their corresponding sinusoidal curves in $\theta - r$ plane will pass through a common point, which is the line in the $\theta - r$ domain.

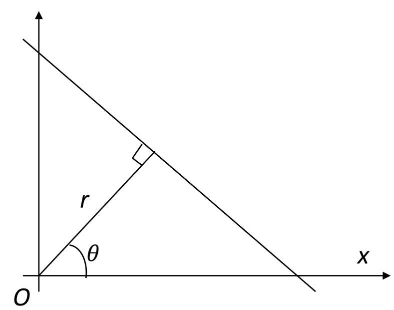

Fig.1. Illustration of Hough transformat

In the Hough transform algorithm, the θ-r parameter space is divided into accumulator cells to form a two-dimensional matrix. The value of the cell is the number of times a mapping line of points in x-y space intersects that cell. Cells receiving a minimum number of "votes" are assumed to correspond to lines in x-y space.

2.2 Segmentation using Partitioning Hough transform

To extract nanofibers, we could use Hough transform to detect lines in SEM images. However, due to the large width, a nanofiber could result in many lines in detection. To overcome this issue, "Skeleton" operation could applied to get the morphological skeleton and then apply Hough transform. However, there is still an issue in the above method. The skeleton of other nanofibers could contribute to the accumulator cell values and may significantly influence the detection accuracy, especially when the density of nanofibers is very large. To overcome this problem, we propose the partitioning Hough transform, where the partitioning is first applied to segment SEM images into multiple images based on connected components and then apply Hough transform to each segmented image. The Partitioning Hough transform is illustrated in Table 1 as follows:

Table 1. Partitioning Hough transform algorithm for nanofiber segmentation.

- Convert the SEM image to a binary image
- Partition the binary image into n SEM images with each having one connected component
- For i=1:n
    - Extract the morphological "skeleton" of image *i*
    - Perform Hough transform on image *i* to get the Hough matrix
    - Identify the peaks from the Hough matrix
    - Detect straight lines based on the peaks and Hough matrix
- End

2.3 Image Simulation

Simulated SEM images of nanofiber reinforced nanocomposites are used to evaluate the proposed method. The image size is 2500×1900. The orientation of the nanofibers follows uniform distribution. Also, the locations of nanofibers follow complete spatial randomness. The length and width of each fiber follow normal distribution with mean of 4 and 120 respectively. Fig.2 shows a simulated SEM image.

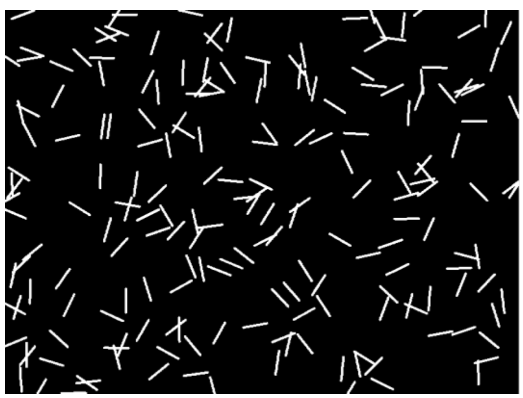

Fig.2. Illustration of simulated SEM image

3 Results and Conclusion

Fig.3 shows the results of Hough transform without partitioning and the partitioning Hough method. The straight lines indicate the nanofibers. There are in total 200 nanofibers in the simulated image. For the Hough transform without partitioning, 184 straight fibers are correctly detected (marked with red and yellow "x" on both end), which indicates an accuracy of 92%. For the partitioning Hough transform method, the accuracy is increased to 97% with in total 194 straight lines have been correctly detected. Note that the partitioning step would result in more significant improvement with larger density of nanofibers.

In conclusion, the developed method based on Hough transform is very effective and efficient in the nanofiber segmentation. With this method, nanofibers morphology analysis can be automatically implemented. The improvement and application of this method to real SEM images will be left to our future work.

(a) (b)

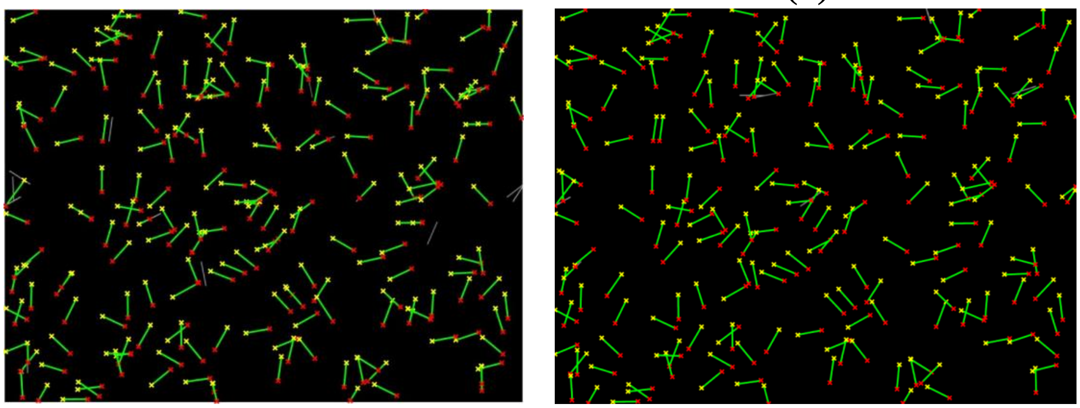

Fig.3. Segmentation results for (a) Hough transform without partitioning and (b) partitioning Hough transform method.

4 Reference

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