

# Studies on Automatic Measurement Technology for Surface Braided Angle of Three-Dimensional Braided Composite Material Performs

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**Abstract**—This paper describes a new measuring algorithm for three-dimensional (3-D) braided composite material. Braided angle is an important parameter of braided composites. The objective of this paper is to present an automatic measuring system. In the paper, the algorithm is performed by using vc++6.0 language on PC. An advanced filtered algorithm for image of 3-D braided composites material performs has been developed. The procedure is completely automatic and relies on the gray scale information content of the images and their local wavelet transform modulus maxims.

Experimental results show that the proposed method is feasible. The algorithm was tested on both carbon-fiber and glass-fiber performs.

**Keywords**—Three-Dimensional composite material, Mathematical morphology.

## I. INTRODUCTION

CONVENTIONAL measurements used in composite material tests include: surface-bonded resistive strain gages, extensometers, and linear variable differential transducers (LVDTs).

3-D braiding can be characterized as two-step, four-step, and multi-step processes. The number of steps refers to the number of movements required for the yarn carriers to return to their original positions.

The biggest automatic braided machine in China based on 4-step was made by Tianjin Polytechnic University in 2003. It has produced variable perform of 3-D braided composites material.

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In the recent years there has been much work about 3-D braided composites material analyzed. Based on early research, a lot of work has focused on the mechanical analysis [1]. However, the properties of 3-D braided composites material depend most of all on the total volume fraction of all fibers and the proportions of the fibers that point in various directions. It is well known that the total volume fraction has close relation to integral structures. Various process models have been derived to describe the complex unit cells of 3-D braiding [2]. The relations between the surface yarn angle of inclination and the Fraction has close relation to relation to integral structures. Various process models have been derived to describe the complex unit cells of 3-D braiding [2]. The relations between the surface yarn angle of inclination and the internal yarn angle of inclination have been researched [3].

The braided angles of 3-D braided material perform is defined as follow: It is a angle which was formed by braided yarns along braided direction in surface. The Fig. 1 shows the surface graphics of 3-D braided material perform under ideal condition.  $\theta$  means the braided angle.

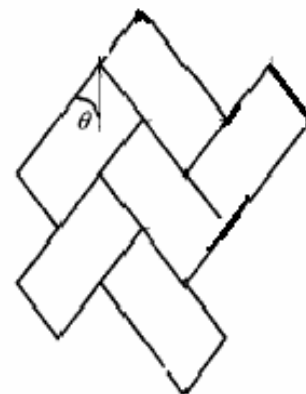


Fig. 1 Perform surface graphics on ideal condition

## II. THE IMAGE ACQUISITION SYSTEM

The surface image testing system diagram for 3-D braided composite material perform is described as Fig. 2. The surface image of perform was collected by area CCD camera in this system. The digitizer board receives CCD camera video signal. The digitizer board collects image at 10MHz-30MHz frequencies.

The CCD video camera recorded the surface light intensity pattern as varying levels of gray. The gray level of each pixel was assigned an integer value from 0 to 255 that were proportional to the light intensity received from the surface of the test object. The lowest black was assigned 0, and the white was assigned 255, with values between representing different shades of gray. The integers representing the light pattern of the test object were assigned pixel locations based on an X-Y coordinate system that corresponded to the actual location on the test object. The digital value will be stored in frame memory of digitizer board. Through software, digital value in frame-memory of digitizer board is sent to D/A convert at the same time. As D/A converter passing data to monitor at constant speed of television, monitor shows the image. The signal processor can control active image halt in any time. It is called "frozen". After freezing on monitor, we can always show frozen image and then PC will read data from frame-buffer. The PC calculates braided angle through software.

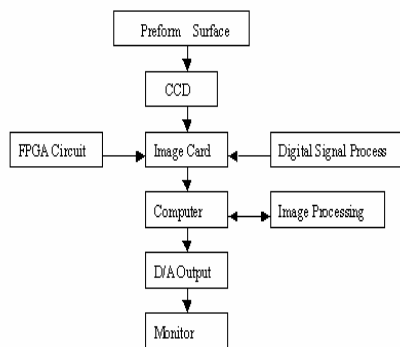


Fig. 2 The diagram of 3-D braided perform image process system

## III. MATHEMATICAL MORPHOLOGY AND MEDIAN FILTERS

The theory of mathematical morphology consists of image transformations that are based on set-theoretical, geometrical and topological concepts [4]. Mathematical morphology is useful for the analysis of the geometrical structure, the reduction of clutter, and the implementation of image

enhancement and segmentation. It is used widely now for image analysis purposes.

We define a discrete median filter by considering a uniform discrete measure  $k$  defined on a finite number of points  $\{x_i | i=1 \dots N\}$ . This means that  $k$  is defined by  $|\{x_i\}|_k = 1$ , which is to say that Dirac masses  $\delta_i$  exist at each point  $x_i, i \in \{1 \dots N\}$  by  $P(N)$  and the number of elements in  $P \subseteq P(N)$  by  $\text{card}(P)$ . Since  $\text{card}(P) = |P|_k$ , we will suppress the  $k$ -notation that is favor of the more transparent "card (P)," but one should remember that the  $k$  measure is still there. Here are the definitions of the two discrete median filters:

$$\text{Med}u(x) = \sup_{\substack{p \in (N) \\ N/2 \leq \text{card}(p)}} \inf_{i \in P} u(x - x_i) \quad (1)$$

$$\text{Med}^-u(x) = \inf_{\substack{p \in (N) \\ N/2 \leq \text{card}(p)}} \sup_{i \in P} u(x - x_i) \quad (2)$$

When  $k$  was continuous, we could replace "  $|B|_k \geq 1/2$ " with, "  $|B|_k = 1/2$ ", but this is not directly possible in the discrete case, since  $N/2$  is not an integer if  $N$  is odd. To fix this, we define the function  $M$  by  $M(N) = N/2$  if  $N$  is even and  $M(N) = (N/2) + (1/2)$  if  $N$  is odd. Now we have

$$\text{Med}u(x) = \sup_{\substack{p \in (N) \\ \text{card}(P) = M(N)}} \inf_{i \in P} u(x - x_i) \quad (3)$$

$$\text{Med}^-u(x) = \inf_{\substack{p \in (N) \\ \text{card}(P) = M(N)}} \sup_{i \in P} u(x - x_i) \quad (4)$$

The fact that we can replace "  $\text{card}(P) \geq N/2$  " with "  $\text{card}(P) = M(N)$  " has been argued elsewhere for the continuous case; for the discrete case, it is a matter of simple combinatorics. Given any  $x$ , let  $y_i = u(x - x_i)$ . After a suitable permutation of the  $i$ 's, we can order the  $y_i$  as follows:  $y_1 \leq \dots \leq y_M \leq \dots \leq y_N$ . Then for  $N$  even,

$$\{\inf_{i \in P} y_i | N/2 \leq \text{card}(P)\} = \{\inf_{i \in P} y_i | \text{card}(P) = M\} = \{y_1, \dots, y_{M+1}\} \quad (5)$$

$$\{\sup_{i \in P} y_i | N/2 \leq \text{card}(P)\} = \{\sup_{i \in P} y_i | \text{card}(P) = M\} = \{y_M, \dots, y_{N+1}\} \quad (6)$$

and  $\text{Med}u(x) = \text{Med}^-u(x) = y_M$ . This shows that  $\text{Med}u(x) = \text{Med}^-u(x)$ . If and only if  $N$  is odd.

$$\{\inf_{i \in P} y_i | N/2 \leq \text{card}(P)\} = \{\inf_{i \in P} y_i | \text{card}(P) = M\} = \{y_1, \dots, y_M\} \quad (7)$$

$$\{\sup_{i \in P} y_i | N/2 \leq \text{card}(P)\} = \{\sup_{i \in P} y_i | \text{card}(P) = M\} = \{y_M, \dots, y_N\} \quad (8)$$

This discussion shows that the definition of the discrete median filter  $Med$  corresponds to the usual statistical definition of the median of a set of data: If the given data consists of the numbers  $y_1 \leq y_2 \leq \dots \leq y_N$  and  $N=2n+1$ , then by definition, the median is  $y_{n+1}$ . In case  $N=2n$ , the median is  $(y_n + y_{n+1})/2$ .

The discrete median filters can also be defined in terms of a non-uniform measure  $k$  that places different weights on the points  $x_i$ . To see what this does, assume that the weights are integers  $k_i$ , so  $|\{x_i\}_k = k_i$ . Then  $k$  has total  $\sum k_i$ , and the condition  $\text{card}(P) \geq N/2$  is replaced with  $|P|_k \geq K/2$ . As before, let  $y_i = u(x - x_i)$  and display the data set as  $y_1 \leq y_2 \leq \dots \leq y_N$ . Then  $Med_k u(x) = y_j$ , where  $j$  is the largest index such that  $k_j + \dots + k_N \geq N/2$ .

Finally, we wish to show that the discrete median filter  $Med$  is a cyclic operator on discrete image. To be precise, we assume that the digital image  $u$  has been periodized so that we have a  $C$ -periodic digital image. Assume that the original image defined on hypercube  $[0,1]^N$  contained  $n$  pixels. Then the total number of the gray levels is bounded by  $n$ . Since a median filter  $Med$  is contrast invariant, the gray levels of  $Med u$  are among the original ones. The same is true for them and iteration  $Med^k u$ . Since that maximum number of different realizations is  $n^n$ , after  $n^n$  iterations, there will be two identical images among the images  $Med^k u$ ,  $k \in \{1, 2, \dots, n^n\}$ . Thus,  $Med$  is cyclic. As a simple example, consider the chessboard image, where  $u(i, j) = 255$  if  $i+j$  is even and  $u(i, j) = 0$  otherwise. When we apply the median filter that takes the median of the four values surrounding a pixel and the pixel value, it is clear that the filter "reverses" the chessboard pattern. Indeed, any white pixel (value 255) is surrounded by four black pixels (value zero). So the median filter transforms the white pixel into a black pixel. In the same way, a black pixel is transformed into a white pixel.

#### IV. EXPERIMENTAL RESULTS

In order to test the algorithm and demonstrate its feasibility for different type of images preliminary results are presented in this section. The 3-D braided performs were fabricated on the 3-D braiding machine, which was developed at the Composites Institute at Tianjin Polytechnic University. All perform images tested are  $512 \times 512$  pixels and were extracted from larger perform images to reduce processing time and disk usage. The algorithm is performed by using VC++6.0

language on PC. The measuring results are stored as files for database and can be made out the value of every braided angle, bar chart, power spectrum and so on [5].

The principal parameters to be specified by the users are the number of levels of wavelet decomposition ( $L$ ) and the value of  $k$ . The wavelet decomposition is carried out up to the second level.

A schematic overview of our method is as follows:

- (1) Extracting a template image from filtered image of perform.
- (2) For template image and sub-image, compute correlation coefficient.
- (3) A threshold  $T_c$  is applied on correlation coefficient procedure so as to eliminate non-significant feature points. Then, a match point is recorded. Repeat (2).
- (4) Braided angle is defined as follow:

$$\theta = \frac{\psi}{2} \quad (9)$$

$$\psi = \arccos \frac{(x_4 - x_1)^2 + (y_4 - y_1)^2 + (x_3 - x_1)^2 + (y_3 - y_1)^2 - (x_4 - x_1)^2 + (y_4 - y_1)^2}{2\sqrt{(x_4 - x_1)^2 + (y_4 - y_1)^2} \cdot \sqrt{(x_3 - x_1)^2 + (y_3 - y_1)^2}}$$

Where  $(x_1, y_1)$ ,  $(x_2, y_2)$ ,  $(x_3, y_3)$ ,  $(x_4, y_4)$  are match point positions (see Fig. 3).  $(X_1, y_1)$ ,  $(x_2, y_2)$ ,  $(x_3, y_3)$  and  $(x_4, y_4)$  are in pixels.

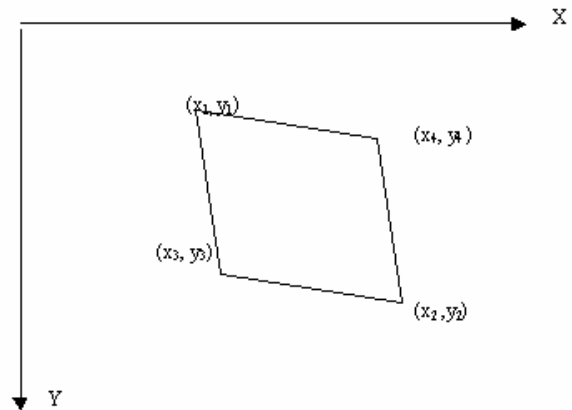


Fig. 3 The diagram of braided angle calculated

Assume that the template image is at the top of left corner. The correlation coefficient is the process of moving the template image around the perform image area and computing the correlation coefficient in the area.

The process was realized with the parameters  $\omega = 160, k=1, T_c=0.82$ . Parts of results are listed in Table I.

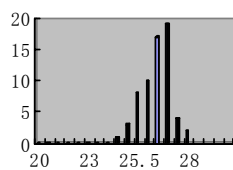
TABLE I

PART OF THE BRAIDED ANGLES OF CARBON-FIBER COMPOSITE MATERIAL  
 PERFORM (UNIT: DEGREE)

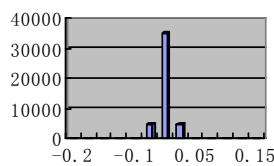
	1	2	3	4	5	6	7	8	Average value
Measured by the algorithm	32.73	31.18	32.11	32.21	31.60	32.45	32.85	32.83	32.25
Measured by protractor	32.1	32.2	32.1	31.4	31.5	31.5	31.7	32.08	31.8
Measured by PC-image software									32.1

Table I shows average values of braided angle which are approximate. However the distribution is uneven for every surface braided angle. This will prove average values of surface braided angle that cannot depict particular mechanical behavior for braided composite material. It is essential that measuring every value of surface braided angle for braided composite material applied.

We use 64 braided angles that were measured on image from composite. The bar chart and power spectrum are presented in Fig. 4a and Fig. 4b.



(a) The bar chart of braided angle for 3-D glass-fiber perform

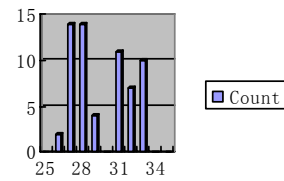


(b) The power spectrum of braided angle for 3-D glass-fiber perform

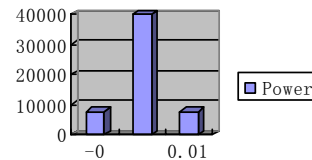
Fig. 4 The bar chart and power spectrum of braided angle for 3-D glass-fiber perform

The process was realized with the parameters  $\omega$   $c=100, k=2, T_c=0.51$ .

We use 64 braided angles that were measured from composite. The bar chart and power spectrum are presented in Fig. 5a and Fig. 5b.



(a) The bar chart of braided angle for 3-D carbon-fiber perform



(b) The power spectrum of braided angle for 3-D carbon-fiber perform

Fig. 5 The bar chart and power spectrum of braided angle for 3-D carbon-fiber perform

Fig. 4a shows the distributing of braided angles (25.5degree-27.5degree) which are even. We can deduce the mechanical properties of composite material made from the perform which will be stable.

Fig. 5a shows the distributing of braided angles (27degree-33degree) which are more uneven than Fig. 4a. We can deduce the mechanical properties of composite material made from the perform which will be more unstable than of composite material made from the perform which is showed as Fig. 4a.

## V. CONCLUSION REMARKS

A system that can automatically measure surface braided angle of 3-D braided composite material perform is presented in this article.

Experiment parameters were presented for braided angle measured in this paper.

As a future work, we will discuss the precise relation between mechanical properties and uneven of surface braided angle.

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**Na Li** was born in Tianjin, P.R. China, in 1981. Currently, she is studying towards master's degree in Computer application technology in Tianjin Polytechnic University in China. Her interest is in the fields of CAD. Now she is making her graduation topic of system of three-dimensional composite.