Analysis of Arrangement Structure for Metal Fiber in Blended Electromagnetic Shielding Fabric

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Abstract— In order to study shielding characteristics of electromagnetic shielding fabric, a method based on computer image analysis is proposed to build an arrangement model of metal fiber. At firstly, some important parameters about shielding effect are summarized, and then a new algorithm based on threshold segmentation for fabric texture extracting is put forward. By ascertaining an optimization threshold, the fabric image is divided and a feature cluster gray image is established. Furthermore, the feature matrix of metal fiber comprising only two gray values which are threshold value and feature value is founded by using normalized method. At last, calculation formulas about metal fiber content per unit area and equivalent thickness are established and the arrangement model of metal fiber is built. Experiments and analysis show that the method given in this paper is able to describe accurately the arrangement of metal fiber in fabric and it will provide a reference for studying properties of electromagnetic shielding fabric.

1. INTRODUCTION

Electromagnetic shielding fabric is an important electromagnetic shielding material. One important way in the electromagnetic shielding fabric production is using metal fiber blending with ordinary fiber, and the key factor to its shielding properties is the arrangement structure of metal fiber. So far the relationship between fabric structure and shielding properties of blended electromagnetic shielding fabric is not clear and definite, one reason is lackin **g** of the effective description of arrangement structure of metal fiber.

The literatures about arrangement structure of metal fiber in blended electromagnetic shielding fabric are few. Most literatures briefly talked about the fabric structure during their research on model [1], properties [2], measurement [3] and related products [4] of electromagnetic shielding fabric, and not involved the specific research on arrangement structure of metal fiber. However, the metal fiber arrangement is of critical importance to the shielding effectiveness. Only when it is reasonably described, can the shielding properties be exactly analyzed.

There are many ways to analysis the structure of ordinary fabric, among them, the automatic distinguish of computer is gradually become a hot research point, which mainly includes Spatial domain method and Frequency domain method [5], and has been widely used in the distinguish of many parameters such as flaws, density, texture and so on. But the application in the arrangement of metal fiber in electromagnetic shielding fabric has not been reported.

In this condition, the structure of blended electromagnetic shielding fabric is analyzed by the method of computer image analysis in this paper. On the basis of the electromagnetic shielding theory and the method of image threshold segmentation, we build a structure model of metal fiber which is suitable for the analysis of shielding effect, and extract some important parameters, providing a reference for the subsequent analysis of shielding mechanism and properties.

2. THEORETICAL ANALYSIS

Research on the arrangement structure of metal fiber in electromagnetic shielding fabric is determined by the electromagnetic shielding theory. The ideal metal shield completes its shielding effect mainly through reflection, multiple reflection and absorption, and a big part is through reflection [6]. The shielding effectiveness SE is decided by the following formula [7]:

$$SE = 168.16 - 10\lg\frac{u_r f}{\sigma_r} + 1.31t\sqrt{f u_r \sigma_r} \quad (\mathrm{dB}) \tag{1}$$

where t represents the thickness of the fabric, μ_r represents the relative permeability, σ_r represents the electrical conductivity, f represents the frequency.

Formula (1) shows that when the frequency is constant, the shielding effectiveness of electromagnetic shielding fabric relates to its relative permeability, electrical conductivity and thickness. According to the electromagnetic shielding theory, the three parameters essentially are determined by the arrangement structure of metal fiber per unit area. Therefore, research on the arrangement structure of metal fiber in electromagnetic shielding fabric is of great significance, providing basis for the subsequent analysis of characteristics on electromagnetic shielding fabric.

3. RECOGNITION OF THE STRUCTURE ON ELECTROMAGNETIC SHIELDING FABRIC

3.1. Threshold Segmentation for Fabric Texture

In order to build an arrangement model of mental fiber, a new algorithm based on threshold segmentation for fabric texture feature cluster is put forward. The steps are as follows: 1) Build an image digitization matrix; 2) Determine the threshold segmentation for fabric texture; 3) Feature cluster normalization; 4) Build the feature matrix; 5) Build the arrangement model of mental fiber.

Suppose that the fabric image is composed of $N \times M$ the lower-left corner vertex o is set as the origin, the horizontal axis labeled the x axis, the vertical axis labeled the y axis and the gray value of pixels is set as the z axis, establish a three-dimensional space coordinate system. Where the values of x, y axis are natural number, the range of z axis is $[0, 255]$. Suppose the coordinate of any pixel is (x, y), gray value is $g(x, y)$, then the gray matrix G_M of the image can be built:

$$G_M = |g(x, y)|_{N\times M} \tag{2}$$

According to knowledge of image processing, the threshold of fabric gray scale can be decided when the average value of the maximum and minimum is worked out. But the result is unreasonable because of the sporadic abnormal high or low gray level points, so the number of the pixels should be considered. This paper uses weighting method to work out the average of gray scale based on the number of all level gray pixels, so the threshold value is determined. Suppose that there are n levels of gray scale, the value of any gray scale is g_n, the number of pixels is P_n, the threshold value is G_t, then:

$$G_t = \sum_{i=1}^{n} \left(g_i \frac{P_i}{N \times M} \right) \tag{3}$$

3.2. The Feature Matrix Describing the Basic Arrangement of Metal Fiber

After the segmentation, the formed feature clusters describing the characteristics of fabric structure should be handled with normalized method. As shown in Figure 1, analysis area is $\Delta x \times \Delta y$, pixels are $p_1, p_2, \ldots, p_c$, the corresponding gray scales are $g_1, g_2, \ldots, g_c$, if $\{g_1, g_2, \ldots, g_c\} > G_a$, then $p_1, p_2, \ldots, p_c$ are the point set of the feature cluster. Classify the pixels which meet formula (5) as well as adjacent to each other into k clusters and there are $m(x)$ pixels in the x cluster, then every feature cluster can be normalized as follow:

$$F(x) = \sum_{i=1}^{m(x)} g(x,i) \tag{4}$$

where in the x cluster, $F(x)$ is the normalized value, $g(x, i)$ is an arbitrary point i. The average value G_a of feature cluster can be obtained from the formula below:

$$G_a = \sum_{i=1}^{k} F(i) \tag{5}$$

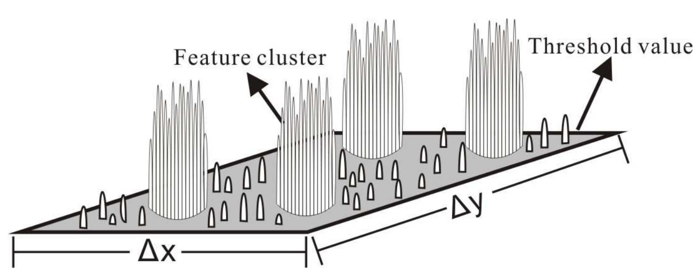

Figure 1: Diagram of texture segmentation and feature cluster.

After the normalization, the basic arrangement structure of metal fiber in electromagnetic shielding fabric can be described by the feature matrix F_M. The matrix contains two elements G_a and G_t, as described below:

$$F_M = \begin{vmatrix} G_a & G_t & \dots & G_a \\ G_t & G_a & \dots & G_t \\ \dots & \dots & \dots & \dots \\ G_a & G_t & \dots & G_a \end{vmatrix}_{N_f \times M_f} \tag{6}$$

where $N_f \times M_f$ are row and column number of the feature matrix.

4. THE BUILT OF ARRANGEMENT MODEL OF METAL FIBER

According to the electromagnetic shielding theory, there are two parameters influencing the electromagnetic parameters in fabric, which are the metal fiber content per unit area and the thickness. The two parameters can be extracted by the method given by the feature matrix (6).

Suppose T_m (g/m^2) is the metal content per unit area, then:

$$T_m = \frac{(D_w + D_v) \times tex \times P}{100} \tag{7}$$

where D_w and D_v are weft and warp densities (yarns/10 cm) recognized by the computer, tex is the fiber fineness unit, P is the metal fiber content (%) in the yarn. For the density analysis, we can consult the autocorrelation method in the literature [8].

Equivalent thickness t_e is converted by the metal fiber content computed by formula (7) and the normal metal volume density. The parameter has an important influence on the skin effect of the electromagnetic wave. If ρ respects the volume density of metal fiber, then:

$$t_e = \frac{T_m}{\rho} \tag{8}$$

5. RESULTS AND ANALYSIS

5.1. Experimental Method

Choose the 60 tex cotton/stainless steel blended yarn with 15% metal content, weave twill, plain and satin electromagnetic shielding fabrics of different densities with the small loom, and then make 15 kinds of rectangular samples each with an area of 25 cm × 20 cm. Obtain the images of the samples with Canon LiDE210 scanner. Write programs based on the method given in the paper with MATLAB7.0, we can get the gray images and arrangement model figures of metal fiber in the output, and then calculate the metal content per unit area of each sample. Take all the kinds of fabric samples, after fully burning, repeated washing and drying, the cotton ashes are filtered out, the residue is the metal fiber. Then we can work out the metal fiber content per unit area based on the weight of the metal fiber and the area of the fabric sample.

5.2. Results

Through the above experiment, we get two metal fiber contents per unit area, one is T'_m obtained by computer analysis and the other is T''_m obtained by burning test. Suppose the error is δ, then:

$$\delta = \frac{|T'_m - T''_m|}{T''_m} \times 100\% \tag{9}$$

Experiment show that error rates of all the results are less than 3%, due to the length limitation of this paper, only 3 representative samples are listed in the Table 1, in which we take the volume density ρ of the stainless-steel fiber as $7.93 \times 10^3\,\mathrm{kg/m^3}$.

Figure 2 shows the local image of twill 1. Figure 3, processed in MATLAB7.0 based on the method given in this paper, shows the arrangement structure of metal fiber of Figure 2. In the Figure 3, we can see the texture structure and the thickness of the metal fiber clearly.

5.3. The Application of the Model

The established model in this paper is to analyze the shielding properties of electromagnetic shielding fabric. Due to the diversity of the fabric structure and complexity of the metal fiber arrangement, we can't calculate the shielding effectiveness directly with formula (1), but can analyze the shielding effectiveness by the method of FDTD in virtue of the method of dividing Yee grid. In

Table 1: Comparison results of metal fiber content per unit area with different methods and equivalent thickness of each fabric sample.

	actual warp density	actual weft density	T'_m	T''_m	t_e	δ
unit	yarns/10 cm		g/m^2	g/m^2	10^{-6} m	%
twill 1	210	182	35.53	36.07	4.45	1.5
plain 1	220	189	36.51	36.11	4.64	1.1
satin 1	198	165	32.66	33.55	4.12	2.7

Figure 2: Local image of twill.

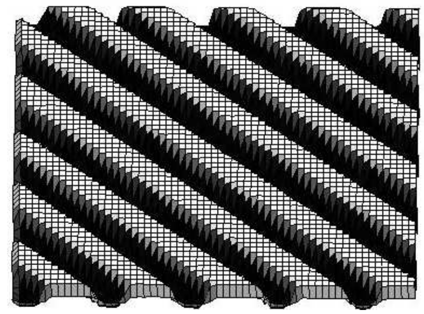

Figure 3: Arrangement structure of metal fiber in Fig. 2.

order to divide Yee grid, it is necessary to describe the geometric structure of the fabric effectively, and obtain fabric structure features related to the arrangement of metal fiber, the model is just built for the task. It extracts the fabric feature cluster, and divided them into different types according to the arrangement of metal fiber, ultimately transform the fabric into the geometric grids constituted by pore area, single yarn area and overlapping area. Based on the electromagnetic parameters of the geometric grid, build the electromagnetic shielding fabric physical model, and finally lay the foundation for analyzing the shielding effectiveness of electromagnetic shielding fabric with the method of FDTD.

6. CONCLUSION

1) The arrangement model of metal fiber, constituted by the threshold values G_t, G_a and equivalent thickness t_e, is able to describe the arrangement structure of metal fiber in electromagnetic shielding fabric better. 2) The new algorithm based on threshold segmentation for fabric texture extracting can distinguish for the plain, twill, and stain weave structure fabrics, and then build a feature matrix of metal fiber arrangement. 3) The given formula to calculate the metal content per unit area and the equivalent thickness of fabric can standardly describe the electromagnetic shielding fabric more accurately.

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REFERENCES

1. Wang, X. C., Z. Liu, and Z. Zhou, "Virtual metal model for fast computation of shielding effectiveness of blended electromagnetic interference shielding fabric," *International Journal of Applied Electromagnetics and Mechanics*, Vol. 44, No. 1, 87–97, 2014.
2. Liu, Z. and X. C. Wang, "Relation between shielding effectiveness and tightness of electromagnetic shielding fabric," *Journal of Industrial Textiles*, Vol. 43, No. 2, 302–316, 2013.
3. Wang, X. C. and Z. Liu, "A new computation of shielding effectiveness of electromagnetic radiation shielding fabric," *Progress In Electromagnetics Research Letters*, Vol. 33, 177–186, 2012.
4. Liu, Z., X. C. Wang, and Z. Zhou, "Automatic recognition of metal fiber per unit area for electromagnetic shielding fabric based on computer image analysis," *Progress In Electromagnetics Research Letters*, Vol. 37, 101–111, 2013.

5. He, F., L. Q. Li, and J. M. Xu, "Woven fabric density measure based on adaptive wavelets transform," *Journal of Textile Research*, Vol. 28, No. 2, 32–35, 2008.
6. Qian, Z. M. and Z. J. Chen, *Electromagnetic Compatibility Design and Interference Suppression Technology*, Zhejiang University Press, Hangzhou, 2000.
7. Liu, Z. and X. C. Wang, "Influence of fabric weave type on the effectiveness of electromagnetic shielding woven fabric," *Journal of Electromagnetic Waves and Applications*, Vol. 26, Nos. 14–15, 1–9, 2012.
8. Gao, W. D., J. H. Liu, B. J. Xu, et al., "Automatic identification of fabric texture," *Cotton Textile Technology*, Vol. 30, No. 4, 218–220, 2002.