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AUTOMATIC RECOGNITION OF METAL FIBER PER UNIT AREA FOR ELECTROMAGNETIC SHIELDING FABRIC BASED ON COMPUTER IMAGE ANALYSIS

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Abstract—Metal fiber content is often a measured parameter for electromagnetic shielding fabric (ESF). A commonly used method is combustion measuring, but measuring speed was slow and measured fabric damaged. This study proposes a new method based on computer image analysis for recognition of metal fiber content per unit area (MFCPUA) of the ESF, which aims at analyzing the MFCPUA without damage and providing a basis for the shielding performance evaluation of the ESF. Local region images of garment or fabric are obtained using high definition shooting system to build a gray matrix model which can describe the image. A recognition algorithm for fabric density based on gray extreme judgment is then given to construct a computation for the MFCPUA. The recognition results obtained with the proposed method is compared with the experimental results from manual combustion measuring and the error reason and the application are also analyzed. Results of experiments and analyses show that the proposed method can identify the local fabric density with lossless and accurately calculate the MFCPUA, which provide a new method for electromagnetic shielding performance evaluation of the fabric and garment by computer technique.

1. INTRODUCTION

Electromagnetic shielding fabric (ESF) is an important shielding material applied to produce garment, composite and soft covering for radiation protection. Metal fiber content per unit area (MFCPUA) is a key factor which influences shielding characteristic of the ESF according to electromagnetic theory. Commonly, the MFCPUA testing

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uses the combustion measuring, but the testing speed is slow, damage large, and testing process inconvenient. However, at present, there are few references in the literature about the MFCPUA detection of the ESF. Most of studies on the ESF focus on shielding characteristic analyses [1], experimental analyses [2], ESF development [3], SE computation [4], model construction [5], transmission characteristic of electromagnetic wave [6], and the ESF application [7]. The MFCPUA recognition and computation is a topic that has not been addressed very often.

A fast and lossless method instead of the combustion measuring for the MFCPUA testing is urgently needed in order to solve the existing problems. Using the computer image processing to measure the MFCPUA is a good selection. The computer image processing possesses a number of advantages, such as fast speed, no damage for fabric, and can overcome the disadvantages of the combustion measuring. Therefore, the computer image processing is a new method to be studied. We first recognize the fabric density by computer image processing, and then calculate the MFCPUA of the ESF.

Computer recognition of fabric density includes spatial domain [8] and frequency domain methods [9]. It has not been reported that computer detection techniques are applied to metal fiber recognition of the ESF within electromagnetic shielding fields. Thus, this paper focuses on automatic recognition of the MFCPUA of the ESF by the computer image analysis.

The ESF image is acquired and treated by linear enhancement, and the gray image matrix is constructed. Then the ESF density is automatically analyzed by a gray extreme judgment. A computation for the MFCPUA is also proposed. The recognition results obtained with the proposed method have been compared with experiments results from annual recognition, and the analyses indicate that the proposed method can correctly recognize ESF density and rapidly calculate the MFCPUA.

2. COMPUTER IMAGE ACQUISITION METHOD FOR ESF DENSITY RECOGNITION

2.1. Computer Image Acquisition Method without Damage

Experimental objects usually are complete electromagnetic shielding garment (ESG) or complete ESF in actual testing. It is undesirable to capture local fabric sample by cutting objects in order to ensure the integrity of the ESG and ESF without damage. We can use the computer technique to acquire local image of the fabric to evaluate the metal fiber content. Figure 1 shows a local image acquisition

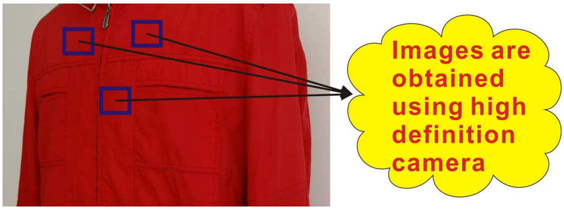

Figure 1. Local image acquisition from complete ESG as worn by a person.

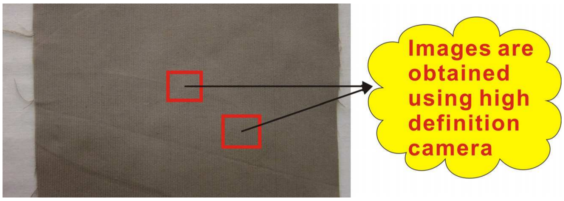

Figure 2. Local image acquisitions from complete ESF as flatted on a table.

from a complete ESG. Figure 2 shows a local image acquisition from a complete ESF. The common point of the two methods is to select a flat local area of the fabric to take a photograph.

2.2. Digital Model of ESF Image

An important step is to construct a digital model of the image after acquiring the ESF image. The considered image is composed of $n \times m$ number pixel points, the bottom left corner of the image is the origin point, the horizontal direction of the image is the axis X, while the vertical direction is the axis Y, the gray value of each pixel is $g(x, y)$, then the fabric image can be expressed by a gray matrix of the fabric image, as shown in Equation (1).

$$\begin{vmatrix} g(x_1,y_1) & g(x_2,y_1) & \dots & g(x_m,y_1) \\ g(x_1,y_1) & g(x_2,y_2) & \dots & g(x_m,y_2) \\ \dots & \dots & \dots & \dots \\ g(x_n,y_1) & g(x_n,y_2) & \dots & g(x_n,y_m) \end{vmatrix} \tag{1}$$

In order to intuitively represent the gray changes of the fabric image, let the value of each point gray in axis Z be [0, 255], then a 3D gray model of the fabric image can be constructed as shown in Figure 3.

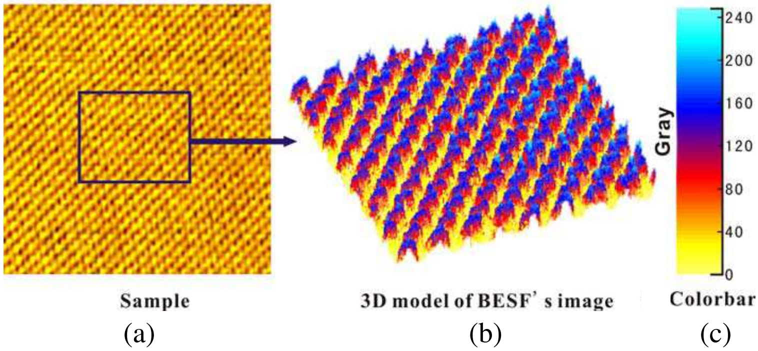

Figure 3. 3D gray model of fabric image.

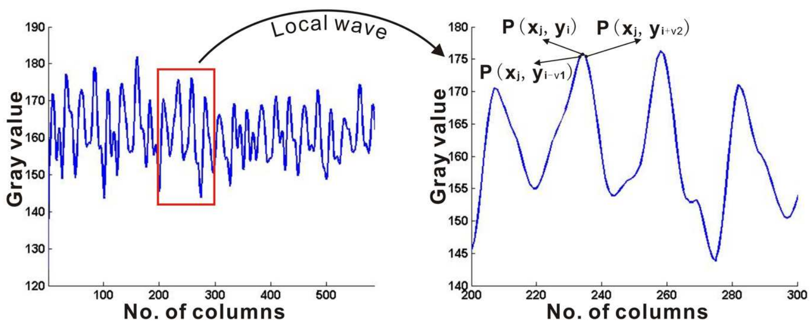

Figure 4. Local gray maximum and minimum value.

As can be seen in Figure 3, the fabric image can be accurately denoted by the gray value after conducting digital treatment, which provides a data model for further parameters analyses.

3. EXTREME JUDGMENT METHOD FOR COMPUTER DENSITY RECOGNITION

A new density recognition algorithm (called extreme judgment) is proposed in this study. A lamp is placed over the fabric, so that the yarns floating the fabric surface have the biggest luminance among yarns, and in the same time the minimum gray value. The yarns below the fabric space have the smallest luminance, and its gray value is the maximum. Therefore, density recognition can be changed to analyze the number of the times of the gray maximum and minimum values in the longitudinal region of the fabric.

For the case in Figure 4, if the point $p(x_j, y_i)$ is a local maximum value, the gray value of the point $p(x_j, y_{i-v1})$ is smaller than that of the point $p(x_j, y_i)$ and the point $p(x_j, y_{i-v1})$ appears at the first time in the left of the point $p(x_j, y_i)$, where $v1$ refers to the pixel number between the point $p(x_j, y_i)$ and the point $p(x_j, y_{i-v1})$. The gray value of the point $p(x_j, y_{i+v2})$ is smaller than the point $p(x_j, y_i)$ and the point $p(x_j, y_{i+v2})$ appears at the first time in the right of the point $p(x_j, y_i)$, where $v2$ is the pixel number between the point $p(x_j, y_i)$ and the point $p(x_j, y_{i+v2})$. Therefore, the point $p(x_j, y_i)$ satisfies the following condition:

$$\begin{cases} g(x_j, y_i) - g(x_j, y_{i-v1}) > 0 \\ g(x_j, y_i) - g(x_j, y_{i+v2}) > 0 \end{cases} \tag{2}$$

If the point $p(x_j, y_i)$ is the minimum value, the following condition is consequently satisfied:

$$\begin{cases} g(x_j, y_i) - g(x_j, y_{i-v1}) < 0 \\ g(x_j, y_i) < g(x_j, y_{i+v2}) < 0 \end{cases} \tag{3}$$

The extreme values of each row and each column are easily judged by the proposed method. The number of maximum and minimum values will be the key data for the recognition of the weft density D_w (ends/10 cm) or the warp density D_v (ends/10 cm) of the ESF.

Equations (2) and (3) represent texture characteristic points of the fabric according to the computer image processing. The characteristic points will be detected so long as the image definition meets the requirements (commonly it is more than 90 dpi). Therefore, we can recognize the fabric density according to the characteristic points of the local fabric of the garment to calculate the MFCPUA.

4. MFCPUA COMPUTATION

4.1. Density Recognition

The ESF density is recognized according to the distribution and number of the extreme values with the proposed method. For the ESF with basic weaves, such as plain weave, twill weave, and satin weave, according to the number of maximum and minimum values in the rows or the columns of the ESF gray image, D_w and D_v can be calculated as follows:

$$D_w = \frac{\sum_{i=1}^{N} W_i}{2 \times N \times L_w} \times 10 \tag{4}$$

$$D_v = \frac{\sum_{i=1}^{M} V_i}{2 \times M \times L_v} \times 10 \tag{5}$$

where W_i is total extreme value of each row, V_i is total extreme value of each column, L_w (cm) and L_v (cm) are the width and the height of the fabric.

4.2. MFCPUA Computation

The metal fiber content with the area of $10\,\text{cm} \times 10\,\text{cm}$ is calculated according to the density definition and the known yarn parameters after obtaining the density of the ESF image. The MFCPUA is obtained after being conversion. If the MFCPUA of the ESF is $M_t\,(\text{g/cm}^2)$, $Y_t\,(\text{tex})$ is yarn density, R_p (%) denotes the percentage of the metal fiber content in a yarn. After extracting the density from the ESF image, the MFCPUA is calculated by:

$$M_t = \frac{(D_w + D_v) \times Y_t \times R_p}{10000} \tag{6}$$

5. RESULT AND DISCUSSION

5.1. Comparison Experiments between Combustion Measuring and Proposed Method

We program a mini-type verification system using Matlab7.0 according to the proposed algorithm. Nine ESFs with different weaves are

Table 1. Comparison results of the MFCPUA with different methods.

Sample code	weave	Fabric density	M_t (Computer recognition)	M_t' (Manual recognition)	Error δ
		ends/10 cm	10^{-4} g/cm^2	10^{-4} g/cm^2	%
S1	plain	298 × 239	16.11	0.001592	1.20
S2	plain	265 × 202	14.01	0.001414	0.90
S3	plain	232 × 169	12.03	0.001192	0.95
S4	twill	278 × 242	15.6	0.001587	1.70
S5	twill	249 × 220	14.07	0.001384	1.60
S6	twill	219 × 198	12.51	0.001231	1.56
S7	satin	269 × 237	15.18	0.001476	2.78
S8	satin	242 × 216	13.74	0.001337	2.69
S9	satin	213 × 195	12.24	0.001255	2.51

selected as samples, its materials are 15% stainless steel fibers and cotton fibers, its weaves are plain, twill and satin, the yarn linear density is 20 tex. A high definition camera (SONY NEX-6) is used to capture the digital images of samples. Then the computer automatically selects a smooth region to recognize. The density and the MFCPUA of the samples are recognized automatically by computer and the results are listed in Table 1.

We select the same samples in above experiments in order to examine the accuracy of the proposed method. The area of samples is $50\,\text{cm} \times 50\,\text{cm}$ (S, cm^2). The samples are burned and then washed in a beaker repeatedly, and the residual materials are the stainless steel fibers. The stainless steel fibers are dried and weighted, the weight is obtained and noted as $W(g)$. Let the MFCPUA be M_t' (g/cm^2) that can be calculated as:

$$M_t' = \frac{W}{S} \tag{7}$$

Let the error between M_t and M_t' be δ that can be expressed as:

$$\delta = \frac{|M_t - M_t'|}{M_t'} \times 100\% \tag{8}$$

As shown in Table 1, the error values δ of each sample are less than 3%. The results proved that the proposed algorithm was accurate.

5.2. Relations between Total Density and MFCPUA Obtained by Computer

From Equation (8), the content of metal fiber associates to the total density of the ESF linearly under certain yarn parameters. The results in Table 1 are also consistent with the conclusion. Let the total density be D_t, and $D_t = D_w + D_v$. According to the values of D_w and D_v in Table 1, the variations of the total density and the MFCPUA are obtained as shown in Figure 5. It can be noticed that the metal content is directly proportional to the total density under the certain yarn parameters whatever the fabric weaves are.

Figure 6 shows a relation between the total density and the metal fiber content of the samples with different weaves. For the same samples, the total density associates to the metal fiber content linearly.

5.3. MFCPUA Obtained with Computer Image Analysis Role on SE Measurement

The MFCPUA influence on the SE has an important meaning. After experiments, we find that the MFCPUA is proportional to the SE, as shown in Figure 7.

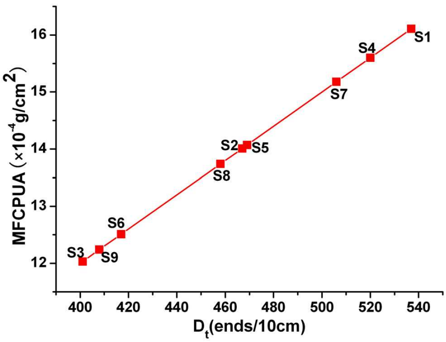

Figure 5. Relation between the total density and the MFCPUA (The yarn linear density: 20 tex, metal fiber content of single yarn: 15%).

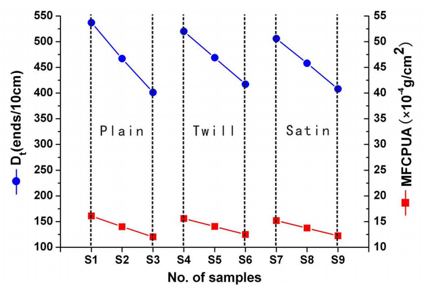

Figure 6. Variation of the fabric with different weaves.

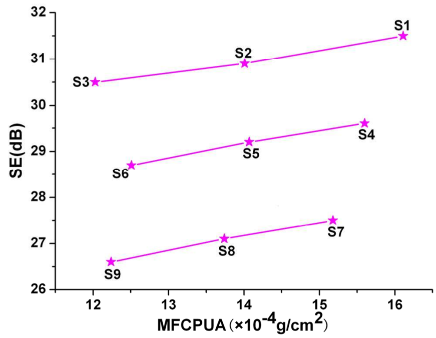

Figure 7. Relation between metal content and the SE (f = 2.3 GHz).

Figure 7 illustrates that the metal fiber content associates with the fabric SE. The SE increases with the increase of the metal fiber content under the same weaves fabric conditions. Therefore, the fabric SE can be evaluated by recognizing the MFCPUA, which is a new evaluation method for the ESF and the ESG.

The experiments mentioned above prove that the metal content associated the SE linearly under the same weaves fabrics. However, for different weaves samples, the metal content does not associate with the SE linearly. The SE also relates to the weave structure of the fabric [10]. Figure 7 also illustrates the results. The SE values of the plain weave fabric (S1, S2, S3), the twill weave fabric (S4, S5, S6), and the satin weave fabric (S7, S8, S9) are within different levels. The metal contents of samples that weaves are different and densities are similar, such as samples S3, S6, S9 are approximate, but the SE values are different.

5.4. Proposed Method Application Analysis on Computer Image Processing

Though the combustion measuring is a common method to test the metal fibre of the ESF, there are a number of disadvantages. The metal surface produces oxidation under high temperature, and it is difficult to completely remove a little ashes adhering on the fibre using filtering and washing ways, making the weight of the metal fibres has errors. The computer recognition does not produce the errors motioned above. The testing results are more accurate than that from the combustion measuring as long as the operation is accurate. The computer testing method does not damage the fabric or the garment, and meet the requirements of random fabric and garment testing in actual wearing, making it has good application.

In addition, Equations (2) and (3) prove that the proposed method recognizes the extreme value of characteristic point location of the fabric to judge the density using the computer technique. The proposed method does not produce recognition error because of the fabric weave change. The proposed method can apply to most of ESFs, which is verified from testing results of the plain weave, twill weave and satin weave fabrics in this study. Thus, the proposed algorithm possesses wide application and strong practicability.

The MFCPUA recognition has an important reference value for further model construction of the ESF. The shielding function of ESF is mainly determined by its conductivity and magnetic permeability according to the electromagnetic theory [11]. The values of the two parameters are determined by the MFCPUA of the ESF. Therefore, giving an equivalent metal shield model can describe the metal

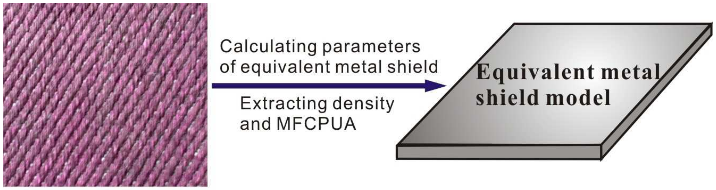

Figure 8. Construction idea of equivalent metal shield model of the ESF.

arrangement structure of the ESF for further analyses of the SE performance. Figure 8 illustrates a construction idea of the equivalent metal shield model based on the proposed algorithm.

6. CONCLUSION

1) The smooth region images of the ESF and ESG are obtained without damage using the computer recognition technique and a gray matrix of the image is constructed.

2) The ESF density is automatically recognized using an extreme judgment method, which lays a foundation for the computation of the MFCPUA.

3) The given computation based on the fabric density and yarn parameters can accurately and rapidly analyze the MFCPUA.

4) The proposed algorithms provide a new method for the performance evaluation of the ESF and the ESG without damage.

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