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Pilling evaluation of patterned fabrics based on a gradient field method

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An objective method for the detection of pills on different kinds of patterned fabric based on image analysis techniques has been developed. The proposed method for pilling evaluation includes the 3D reconstruction of a fabric surface with pills and the detection of pills of fabrics with various patterns. Shadows created by pills with lateral illumination of the samples, while images of the samples are being captured, are the basic element for the 3D reconstruction of the fabric surface using a gradient field method. By using this method, the effect of fabric pattern on the results of 3D reconstruction is suppressed. The reconstructed fabric surface enables effective segmentation of pills from a fabric texture using simple image processing tools. Important characteristics of pills, such as number, area, perimeter, density and contrast, are extracted for the objective pilling evaluation. The results show that the proposed method is applicable for the evaluation of pilling not only for unicolor fabrics but even for fabrics with various kinds of patterns.

Keywords: 3D surface reconstruction, Fabric pilling, Gradient field method, Patterned fabric, Pills detection

Textile fabric pilling is a well-known phenomenon in quality control in the textile industry. Fabric surface pilling is a considerable problem evolving during the everyday wearing and washing of clothes. An evaluation of fabric pilling is one of the most important factors in judging material properties. The traditional subjective method of the fabric pilling evaluation is still used in the textile industry. The subjective method is based on a human expert's comparison of a series of standard pilling images with samples according to standards EN ISO 12945-2 and ASTM D4970. However, this judging by the human eye is disadvantageous due to the inaccuracy of the rating results[1]. Due to this a good deal of research is needed to develop an objective method for pilling evaluation.

Since a long time, many studies have been carried out to replace subjective methods with more accurate and reliable objective method. Image processing methods are a popular and widely used tool for the objective pilling evaluation of unicolor fabrics. Nevertheless, simple image analysis methods are not a suitable procedure for the pilling evaluation of fabrics with complex and colorful patterns due to their intrinsic limitations[2]. Pilling can be evaluated using two-dimensional (2D) or three-dimensional (3D) images. In general, an evaluation of 3D images gives better results than those of 2D images for more accuracy and robustness in pill detection[3]. Many studies have tried to segment pills from their fabric structures via various image processing techniques. Corner detectors for finding the crossing points of yarns and for detecting the disturbance in regularity caused by pills in monochromatic images of fabric structure have already been reported[4]. Another study introduces an extraction of pills from an RGB image which is characterized by the edge flow method for a complex fabric[5]. The effectiveness of pill segmentation can be enhanced by analyzing and blending individual RGB channels[6]. Template matching techniques have also been reported[7,8], where pills are modeled using a 2D Gaussian function, and due to different pill sizes, a group of matching filters can be designed for effective pill detection. Other commonly used techniques are based on 2D discrete Fourier transforms (2D DFT) which are capable of dividing the image into two image parts, viz the periodic part which contains the deterministic structure of the fabric and the non-periodic part involving random noise and pills, which is suitable for the segmentation of pills from the structure[1,9]. A wavelet reconstruction scheme, which includes a 2D discrete wavelet transform, has been reported[10-17] to evaluate fabric pilling. Ucar and Boyraz[18] proposed a method for measuring fuzzy fibres (which create pills) in projection images of the fabric using image analysis tools. The pilling evaluation method[19] uses 2D and 3D hybrid imaging techniques. Light-projected image analysis is used to evaluate pilling[20]. The study proposes the use of a special device to acquire projected cross-sectional images of the fabric samples with pills.

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Most of the recapitulating methods presented above tested the pilling segmentation on unicolor fabrics. This is because the detection of pills on a patterned fabric has been relatively problematic in image analysis due to the complexity and difficulty in the process of pill segmentation. In this study, we propose an objective method for the pills detection of various patterned fabrics using the gradient field method for 3D fabric surface reconstruction and simple image analysis tools for pills segmentation, which may be the way to overcome this barrier.

Experimental

Samples

In this study, a representative set of patterned samples was selected and tested for illustration of the method's efficiency. The set includes various patterned fabrics in plain and twill weave with different kinds of material, various grades of pilling and especially with different type of patterns.

For the pilling evaluation experiment, a representative set of four patterned fabric samples was selected, namely one sample in plain weave (S1) and three samples in twill weave (S2, S3, S4) with different patterns such as checked, striped, hounds tooth and salt & pepper. The patterns of the fabric samples S1-S3 are made by multicolored woven technology where warp and weft are composed from more than two kinds of colored yarns. Pattern of the sample S4 is made by smooth printing technology. Firstly, important parameters of the samples, such as composition, type of weave & pattern, technology of pattern production, and area density were studied. The basic parameters of the samples are shown in Table 1. The images of the representative set of patterned samples S1-S4 with pills are illustrated in Fig. 1 (a)-(d).

Image Capturing System

First of all, capturing of the sample images was carried out. The image capturing system was based on the requirements for the application of gradient field method. The requirements included the necessity to create pill shadows. The image capturing system included only a camera, a planar light source and a tripod. First of all, a set of four images for every sample had to be captured to reconstruct the surface in 3D using the gradient field method[21-23]. Therefore, the samples were laterally illuminated by planar light source step-by-step from the four sides, viz from above I_a (image I_a), below I_b (image I_b), the right side I_r (image I_r), and the left side I_l (image I_l). Their images were captured by the camera placed over the sample. Pills as protruding objects created obvious shadows which present the crucial basic element for accurate and effective 3D fabric surface reconstruction and subsequent pill detection.

3D Reconstruction of Patterned Fabric Surfaces

Generally, pills created from a lateral illumination pose a significant problem in pill segmentation. However, the gradient field method requires pill shadows for quality 3D surface reconstruction. The image capturing procedure described above comprised the first necessary step in a quality 3D fabric reconstruction (acquiring the pill shadows). When the set of four images for each of the samples has been prepared, it is possible to create a 3D reconstruction of the fabric surfaces using the gradient field method.

The created shadows of pills represent a change of pixel brightness values in the sample image. The

Table 1—Basic parameters of the representative set of patterned samples

Sample	Material	Weave	Pattern	Technology of pattern production	Area density kg/m^2
S1	Viscose	Plain	Salt and pepper	Woven	0.175
S2	Polyester	Twill	Checked	Multicolored woven	0.193
S3	Wool/PES	Twill	Hounds tooth	Multicolored woven	0.206
S4	Cotton	Twill	Striped	Printed	0.236

Fig. 1—Images of patterned samples after pilling resistance test

change of pixel brightness values can be expressed using a gradient in horizontal and vertical directions in the sample image. In this work, the gradient (g_x) in horizontal direction of the image is obtained by the subtraction of the sample image illuminated from the left I_l with the sample image illuminated from the right I_r. Conversely, the gradient (g_y) in vertical direction of the image is acquired by the subtraction of the sample image illuminated from above I_a with the sample image illuminated from below I_b, as shown below:

$$g_x=I_l-I_r, \quad \ldots (1)$$

$$g_y=I_a-I_b. \quad \ldots (2)$$

The gradient field method creates a 3D surface reconstruction from such images. 3D surface reconstruction of the samples was achieved using MatLab software and an algorithm as given by Agrawal *et al*[23]. The principal aim of the method is to make a gradient field of the image integrable. If the gradient field is integrable, it is possible to reconstruct the surface using the Poisson solver and Frankot-Chellappa algorithm[22]. The efficiency of the method on a unicolor fabric has already been introduced in study[21].

Pills Detection Using Image Processing Techniques

The procedure of simple and fast pill detection in 3D images is performed as described hereunder. The 3D reconstructed surface can be considered as a 2D gray level image, where the amplitude represents the gray level. However, there is random noise in the gray level image which can be removed by the simple noise reduction techniques such as a Gaussian filter.

In the filtered 2D gray scale level images of the samples, pills can be separated from the background surface by using a local thresholding algorithm according to the *Niblack* method[25]. The principal of thresholding algorithm is based on sliding a rectangular window over the gray level image. The *Niblack* method counts the local threshold for each pixel according to the local mean and standard deviation of all the pixels in the pixel surroundings of the window. The resulting binary image contains extracted white objects as pills and the black background as a fabric surface. Subsequently, in the binary images of the samples it is easy to extract basic and important pill characteristics.

Results and Discussion

Suppression of Effect of Fabric's Periodic Pattern

Generally, the pills detection on patterned fabrics is very difficult due to their complexity and the scope for incorrect segmentation of pills of the patterned fabrics during a simple image analysis. For clarity, the efficiency of 3D fabric reconstruction using the gradient field method is shown on the set of four images of patterned Sample S2 illuminated from four sides [Fig. 2 (a)-(g)]. The results of 3D fabric surface reconstruction by the gradient field method have shown that the effect of a fabric's periodic pattern is suppressed in the 3D surface and the method could be effective for reconstruction of patterned fabrics. Suppression of the effect of the fabric's periodic pattern is obvious in the gradient images (g_x), (g_y) of the Sample S2 [Fig. 2 (e) & (f)]. In these gradient images (g_x) and (g_y), pills are emphasized and their detection is quite simple in the

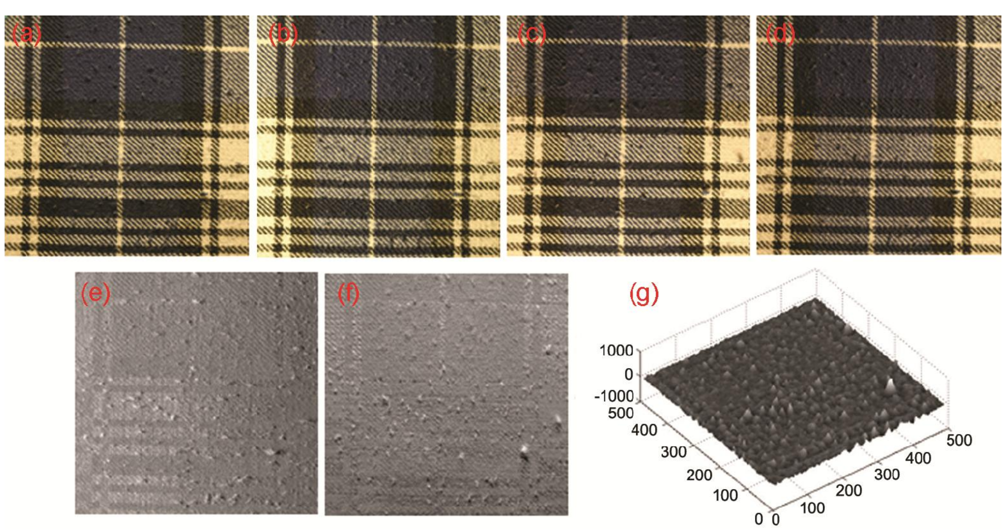

Fig. 2—Set of four images of patterned Sample S2 illuminated from (a) above I_a, (b) left I_l, (c) below I_b and (d) from right side I_r. Gradient images (e) in horizontal direction g_x, & (f) in vertical direction g_y, and (g) the reconstructed surface of Sample S2 in 3D image

reconstructed 3D fabric surface [Fig. 2 (g)]. Specifically in the method, pills are clearly differentiable even on a border of color transition in a pattern in a reconstructed 3D fabric surface and it presents a significant advantage for accurate and reliable pill segmentation. The simple and effective suppression of the influence of patterns on pill segmentation is a novelty among pilling evaluation methods.

Efficiency of Pills Detection in 3D Fabric Surfaces

In this study, the simple tools of the image processing procedure have been used for reliable pills detection. For keeping of an objective procedure of pills segmentation, the automatic thresholding method *Niblack* was used and it proved to be quite accurate tool for pills segmentation from the fabric surface. The efficiency of described method is illustrated in Fig. 3 where the original set of samples (a1)-(a4), the

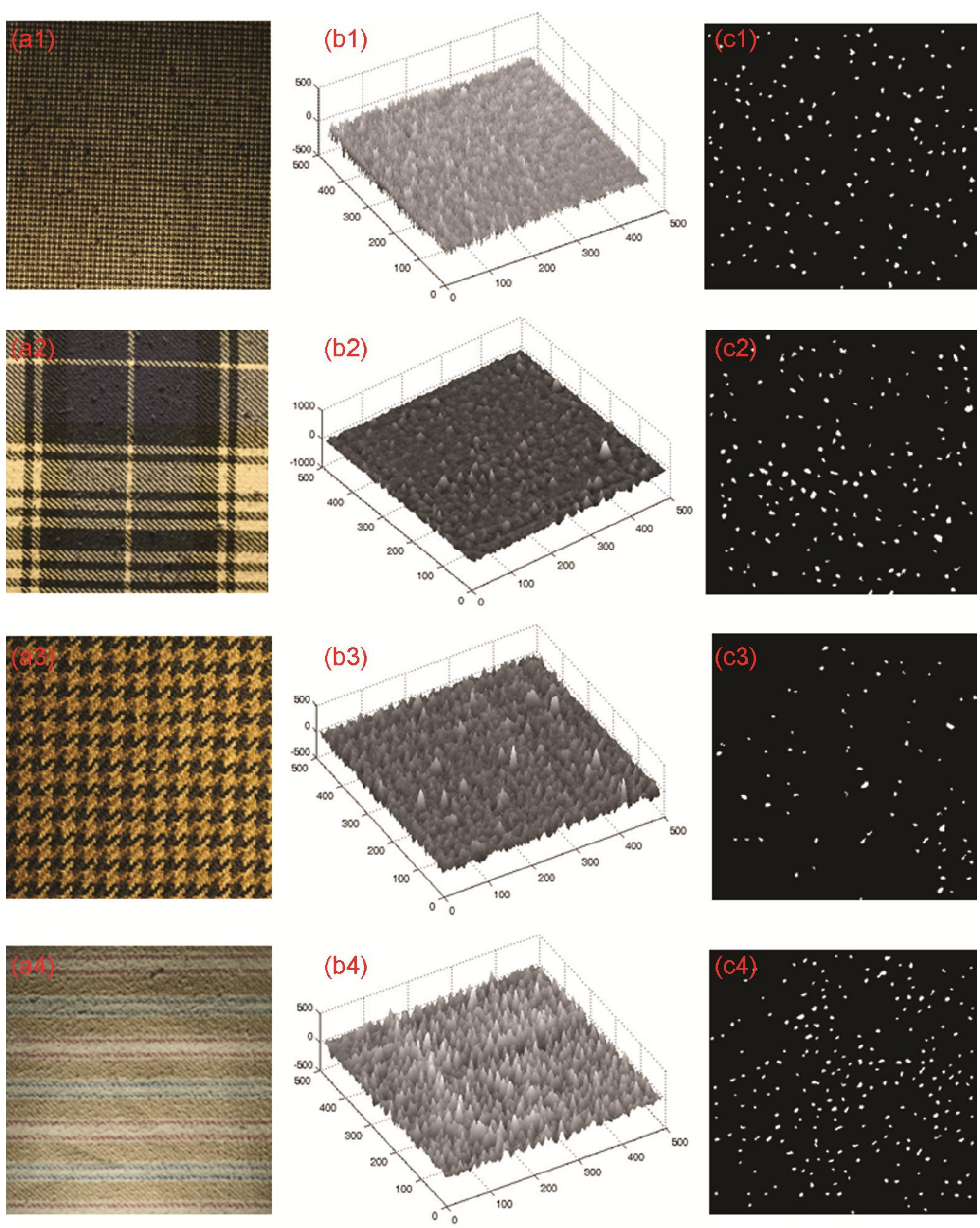

Fig. 3—(a1)-(a4) Representative set of the images of samples S1-S4, (b1)-(b4) 3D reconstructed surfaces of the samples created by the gradient field method, and (c1)-c(4) detected pills in binary sample images as the result of the pills segmentation

Table 2—Pill characteristics of representative set of the samples

Pill characteristic	Sample			
	S1	S2	S3	S4
Number of pills	154	157	75	226
Average pill area, mm^2	0.64	0.69	0.56	0.55
Minimal pill area, mm^2	0.26	0.26	0.26	0.26
Maximal pill area, mm^2	1.60	2.01	1.85	1,78
Standard deviation of area, mm^2	0.24	0.39	0.35	0.24
Total pills area, mm^2	100.47	102.45	42.57	124.47
Average pill perimeter, mm	2.78	2.99	2.68	2.53
Minimal pill perimeter, mm	1.51	1.51	1.51	1.51
Maximal pill perimeter, mm	4,83	6.98	5.37	6.12
Standard deviation of perimeter, mm	0.67	0,99	0.92	0.74
Pilling density, 72×72 mm^{-1}	0.03	0.05	0.02	0.07
Contrast	1.16	1.06	1.16	1.20

reconstructed 3D surfaces (b1)-(b4) and final binary images (c1)-(c4) of the patterned samples are shown.

Extraction of Pill Characteristics

In the subjective pilling evaluation, experts assess the grade of pilling of a fabric sample by comparison of the pill characteristics, such as pill density and pill size with standard images[6]. Further important pill characteristics can easily be measured in the binary image of the samples and can be used for an automatic and objective computation of the pilling grade. Important pill characteristics included the number of pills (*N*), the average area (A_A) and the total area of pills (A_T), minimal (A_{min}) and maximal (A_{max}) pill area, the average perimeter of pills (P_A), minimal (P_{min}) and maximal (P_{max}) pill perimeter, the contrast (*C*) of pills and the pilling density (*D*). All the mentioned pill characteristics were computed from binary images of the samples using basic image processing tools in software MatLab. The values of the pill characteristics of the representative sample set are presented in Table 2. In future, the fabric pilling of the samples can be evaluated due to extracted pill characteristics.

The main advantages of the method include the short time of creation of 3D surfaces and data processing, cheap devices for capturing and processing the 3D surface image, using the shadows of pills for the benefit of the 3D surface reconstruction and the elimination of the influence of the fabric pattern on the 3D reconstruction results. The method does not require much time or more expensive equipment, just a camera and light source for capturing the sample image are sufficient. Furthermore, due to the elimination of the influence of the fabric pattern on pills segmentation it is easy to obtain accurate binary images with detected pills by basic image analysis tools and subsequently extracted pill characteristics that are necessary for the objective and automatic computation of the pilling grade. Results of the study show that the proposed method is appropriate not only for the pilling evaluation of unicolor fabrics but even for the pilling evaluation of patterned fabrics in quality control in the textile industry.

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