

Comparison of Two Different Principles of 3D Fabric Surface Reconstruction

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Abstract

This paper compares the efficiency of two different methods for a 3D fabric surface reconstruction with defects. The efficiency of the methods is evaluated according to the accuracy of 3D reconstruction, especially the detection of fabric defects and their respective characteristics. In this case, the defects of mean fabric pills. Pills are small balls of entangled fibers on top of a fabric surface, and they occur on every type of fabric. Using existing methods for objective pilling evaluation, many researchers have tried to find an effective procedure for the detection of pills in a fabric image. It is very important to obtain an accurate method for 3D surface reconstruction and the subsequent detection of pills. In the present study, the methods tested differ in the principle of creation of the 3D surface. The first method (method A) is called the gradient field method, the principle of which is based on the use of the shadows of pills for 3D reconstruction. The second method (method B) uses non-contact laser profilometry for 3D surface reconstruction. A Talysurf CLI 500 instrument was used to trace the surface fabrics and to reconstruct the profile of the fabric surface. The results showed that method A should be more reliable for this purpose.

Key words: pilling, objective evaluation, fabric surface, 3D surface reconstruction.

Introduction

Pilling is one of the properties of garments most often evaluated, related to changes in fabric surface appearance. The property occurs during the common wearing and washing of clothes. Pills represent small balls of entangled fibres protruding from the fabric surface, which are connected with the top of the surface. Approximately up to the end of the 1980s, a subjective method was used for pilling evaluation. However, since the early 1990s, digital image processing techniques have tried to replace the subjective method with more reliable and objective ones. The objective methods have taken advantage of image analysis tools [1].

Generally for objective image analysis we can use two dimensional (2D) [2 - 7] or three dimensional (3D) images [8 - 11]. In the case of pilling evaluation, it is more advantageous to use a 3D image, the reason for which is clear: A 3D surface gives more accurate information about the shape of a surface. The information is very important especially in the case of a fabric with a pattern where using a 2D image is complicated due to the intrinsic limitations of the simple image analysis methods. By using 3D fabric surface reconstruction we are able to suppress the influence of the pattern on pill detection, which is a very important factor for obtaining accurate results [9]. However, not all principles of 3D surface reconstruction are suitable for the reconstruction of a fabric surface with pills. Therefore the selection of a meth-

od for 3D fabric surface reconstruction plays one of the most significant roles in the objective pilling evaluation of 3D surfaces.

The study deals with the testing and comparison of the complexity and efficiency of two different principles of 3D fabric surface reconstruction. The results of the reconstruction are evaluated with regard to the accuracy of fabric defect detection. In the paper, the defects represent the above-mentioned pills. The first principle tested, called method A, is based on the gradient field method. The principle of method A is based on the creation of pill shadows from four sides and reconstruction of the shape of the surface using information about changes in pixel values in the image. Method A requires just a camera, light sources and a special algorithm using the gradient field method for 3D surface reconstruction. The second method, called method B, uses non-contact laser profilometry for 3D surface reconstruction. A Talysurf CLI 500 instrument was used to trace the surface fabrics and to reconstruct the profile of the fabric surface. The efficiency, complexity and accuracy of the methods tested are judged according to a comparison of results of subjective and objective pilling grades obtained from the methods and to a visual assessment of the precision of pill detection.

Experiment

Materials

Five various types of fabrics were used as a representative set of samples for

testing the two different principles of 3D surface reconstruction. The samples differ in the type of weave, material, weave density, design, colour, pilling grade, and so on. All the samples are woven fabrics. Every sample had a certain number of pills on the top of the fabric surface, which means that the fabrics tested had various grades of pilling.

Firstly the samples were subjectively evaluated by three human experts in accordance with the standard EN ISO 12945-2 [10]. The average value from the ratings was taken as the subjective pilling grade of a sample and was introduced together with the basic parameters of test fabrics S1 - S5 in **Table 1**. Generally the pilling of a fabric is evaluated according to the standard pilling grades - from grade 5 to grade 1, which means from no pilling (pilling grade 5) up to very severe pilling (pilling grade 1). The subjective pilling grades will be compared with the objective pilling grades, which are obtained from the methods tested - it will serve for a determination of the test method's accuracy. Images of a representative set of the fabrics with pills on the top of the fabric surface are illustrated in **Figure 1**. The area of all of the fabrics tested was approx. 5 × 5 cm.

Methods

Two different principles of 3D surface reconstruction were tested and evaluated in the study. The first principle, method A, is based on the gradient field method and reconstructs the surface shape according to the shape of the shadows of an object

Table 1. Basic parameters of a representative set of the fabrics tested.

Sample	Material	Weave	Pattern	Area density, kg/m ²	Weave density warp – weft, cm ⁻¹	Subjective pilling grade
S1	Cotton	Plain	No	0.175	20 - 17	3
S2	Wool/Polyester	Twill	No	0.193	32 - 27	2-3
S3	Cotton	Plain	Yes	0.206	19 - 17	1
S4	Polyester	Twill	Yes	0.197	29 - 26	3
S5	Viscose	Plain	Yes	0.181	32 - 30	3-4

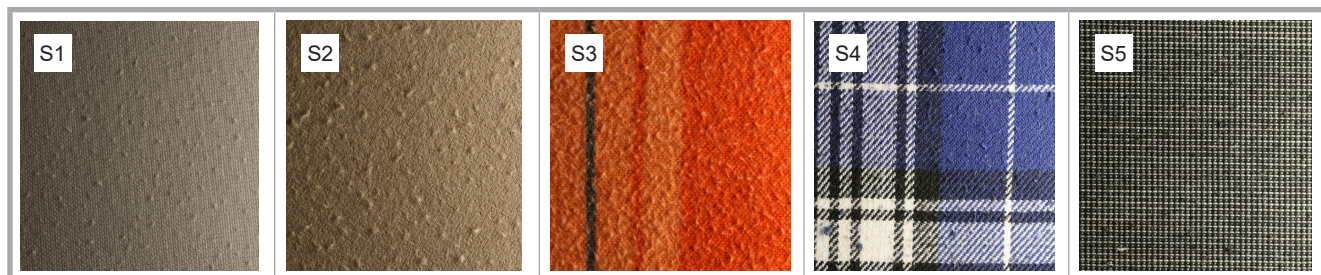


Figure 1. Images of a representative set of test fabrics S1 - S5 with pills on the surface top.

created. The other principle, method B, uses non-contact laser profilometry technology for 3D surface reconstruction. In this case, the capturing of the 3D surface shape is carried out by a Talysurf CLI 500 device. A description of these two methods is as follows:

Method A

The gradient field method was chosen as the first method tested. The gradient field method is based on *Shape from Shading* method – reconstruction of the surface shape according to shadows of the surface slope. The main point of the method comes from the creation of the shadows of an object (pills in this case) by lateral illumination. Due to the lateral illumination of an object, a gradient of the surface is created and shadows of the surface slope represent changes in the brightness of pixels in an object image [13, 14].

For 3D surface reconstruction using the gradient field method, the following

tools are required: a camera, an illumination system and a special algorithm based on the gradient field method. Especially for this purpose, a special illumination system was designed and constructed (Figure 2.a). The illumination system includes four planar light sources of the dispersive type which can be lit up individually. The size of the individual light source is 160 × 70 mm. Imaging of the samples was carried out using a Canon EOS 400D DSLR digital camera. A sample was placed on a base at a distance of 70 cm from the lens of the camera. The lights were placed 10 cm from the edge of the sample and 2 cm over the base at an angle of approximately 45°.

The procedure of 3D fabric surface reconstruction is as follows: First of all, it is necessary to create pill shadows by lateral planar light sources from four sides successively: above, below, from

the right side and finally from the left side. The pill shadows created by lateral illumination from the four different sides are fundamental for effective 3D reconstruction of the sample with pills. During the individual illumination of a fabric, a fabric image is captured by a camera placed over the fabric surface. In this way, a set of four images is created for every fabric. The simple imaging system which was used for the experiment is illustrated in Figure 2.b. The principle of the pill shadow creation from the four sides by a light source is displayed in Figure 2.c.

Images of the samples were stored as image matrices in the RGB scale in the JPG format and cropped to a size of 1500 × 1500 pixels (approximately 50 × 50 mm). Subsequently RGB images of the samples were converted to grey scale images (with 256 grey levels) and the contrast of each of the sample images was enhanced.

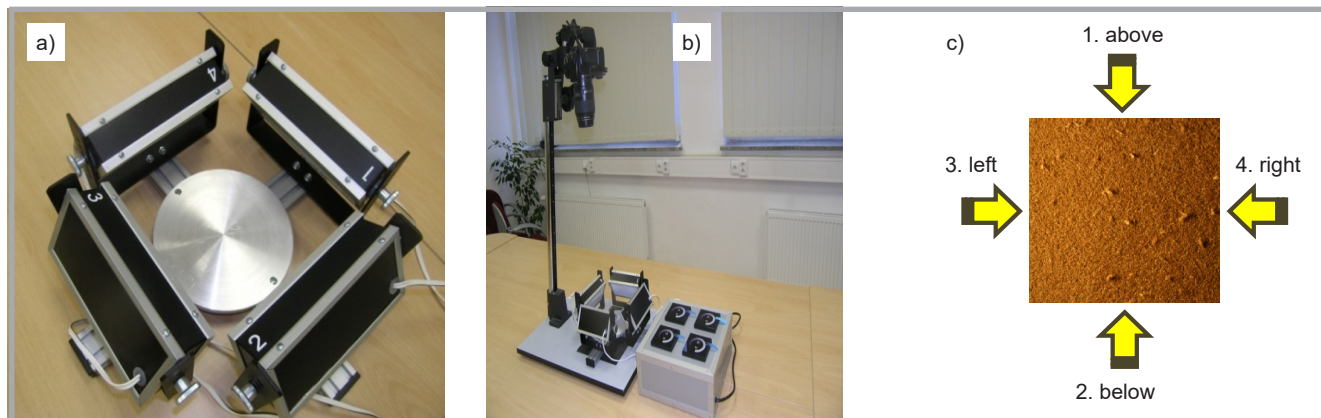


Figure 2. a) Special light system, b) the image capturing system, and c) the principle of pill shadow creation by a light source.

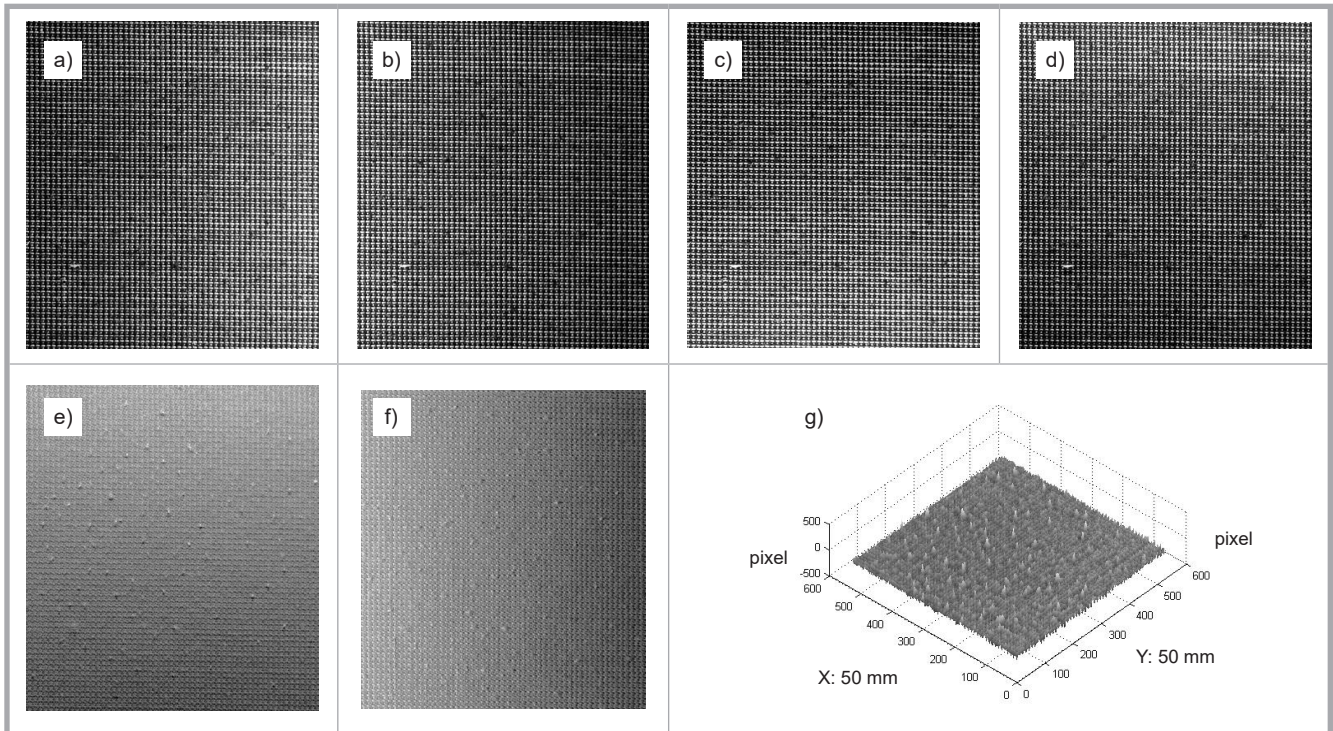


Figure 3. 3D fabric surface reconstruction of fabric S5. The set of four images of the sample illuminated from (a) the right, (b) the left, (c) below and (d) above. Estimated gradient images in (e) the horizontal direction and (f) vertical direction, (g) 3D surface of sample S5.

Two gradient images for each sample were estimated from a preprocessed set of four fabric images. Generally the image gradient ∇f of a grey level image $f(x,y)$ is defined as a vector [15]

$$\nabla f = \begin{bmatrix} g_x \\ g_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (1)$$

The gradient images were estimated by subtraction of the sample images illuminated in the relevant directions, namely

the gradient image in the horizontal direction g_x was acquired by the subtraction of the sample image illuminated from the left side from the sample image illuminated from the right side. Similarly the gradient image in the vertical direction g_y was obtained by the subtraction of the sample image illuminated from above from the sample image illuminated from below.

With just these two gradient images we are able to reconstruct a surface in 3D us-

ing a special algorithm designed in Mat-Lab software. The algorithm is adopted from research study [13] and includes several mathematical functions which are related to an integration of the gradient fields of an image. The algorithm is based on the gradient field method and tries to enforce the integrability to recover integrable surfaces. The point 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 Frankot-Chellappa algorithm. For more information see [13, 14]. The 3D fabric surface reconstruction of one sample using method A took just several seconds. A set of four images of sample S5, two gradient images and final 3D fabric surface obtained from method A, are shown in **Figure 3.a - 3.g**. Due to the principle of the method, the fabric pattern is suppressed (obvious in the gradient images) and pills are emphasized in the 3D fabric surface.

Method B

Technology using non-contact laser profilometry was chosen as the second test method. The method is carried out by a Talysurf CLI 500 device. The basic principle of 3D fabric surface creation comprises laser profilometry – an extraction of individual surface profiles using the laser principle. The 3D surface reconstruction is based on imaging individual sur-

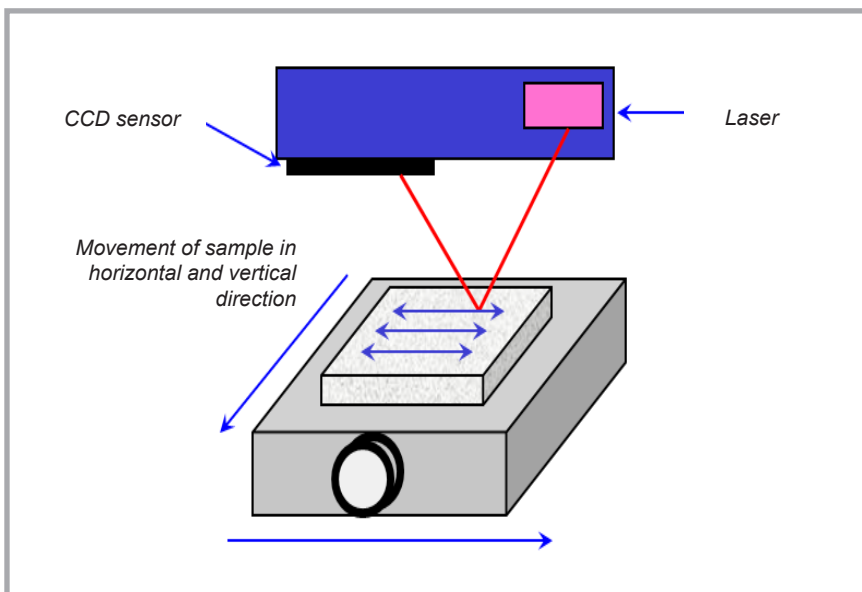


Figure 4. Principle of surface imaging by a Talysurf device.

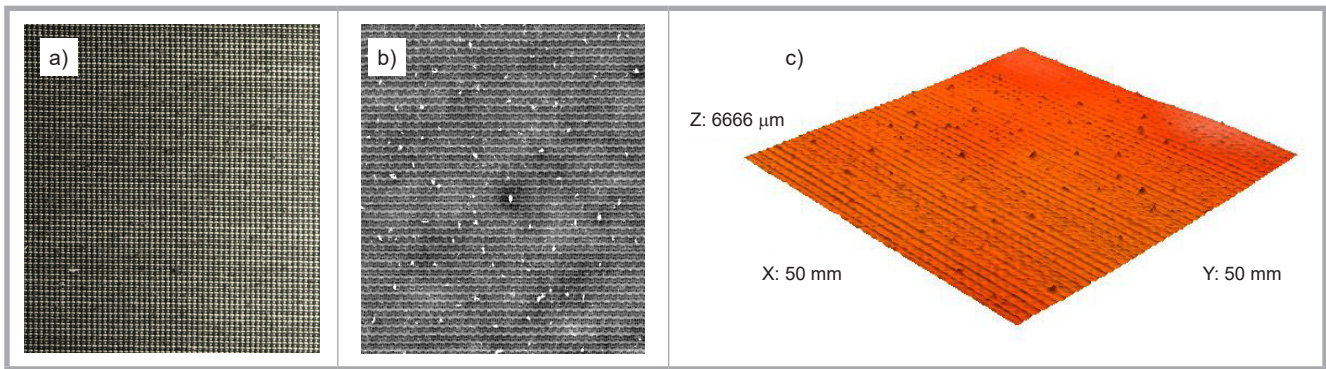


Figure 5. a) Original image of sample S5, b) grayscale image and c) 3D surface obtained from Talysurf device.

face profiles in the length of a sample by a laser which is moving, and the sample is in a stationary position. A 3D surface is created by combining all the measured profiles beneath each other. The principle of imaging the surface shape of an object using the Talysurf device is shown in Figure 4.

The resulting images acquired from the Talysurf are all presented in Figure 5.a - 5.c: An RGB image can be seen of sample S5, a grayscale image and 3D surface. The parameters of the surface imaging for one sample by the Talysurf device are as follows:

- spacing: 30 μm,
- velocity of imaging: 10 mm/s,
- imaging time: 4 hrs and 30 min.

Due to the principle of surface imaging by laser, the pattern and colour of the fabric is suppressed in a 3D surface. Therefore these factors do not have an influence on subsequent pill detection. This effect is very important for accurate pilling evaluation of patterned fabrics.

Pill Detection in Estimated 3D Fabric Surfaces

The accuracy of pill detection in a fabric image plays one of the most important roles in pilling evaluation. According to a visual comparison of the pill detection results with the original sample images, we can judge the method's accuracy as well. The next step will be the detection of pills in the 3D fabric surfaces obtained. The pill detection is carried out by image analysis techniques, especially using a local thresholding algorithm according to the *Niblack* method [16]. The *Niblack* method counts the local threshold for each pixel according to the local mean μ and standard deviation σ of all the pixels in the pixel surroundings (i,j) of a window w . For calculation of the

local threshold of an image, we need to set two parameters: the size of the window $b \times b$ and thresholding coefficient k . Values of the parameters $k = 0.23$ and $b = 9$ were set up experimentally. The parameter values proved to be the most appropriate option for all the test samples according to visual judgment – where detected pills correspond to those in the original sample images as much as possible (pills detected are marked by red colour in the image). Computation of the local threshold $T(x,y)$ for each pixel with coordinates x,y is given by the expression

$$T(x,y) = \mu_{b \times b} + k \sigma_{b \times b}. \quad (2)$$

The result of the procedure described is a binary image of the fabric where the white objects represent detected pills. A comparison of the resulting images from the analysis of sample S5 (3D surfaces, their binary images and grayscale images with pills marked by red colour) obtained from test methods A and B is illustrated in Figure 6.a - 6.g (see page 42).

Results and discussion

This study tests and compares the efficiency of two different methods for 3D fabric surface reconstruction. Just a visual comparison of 3D surfaces obtained and their binary images is not sufficient to determine which 3D method is better for this purpose. Generally the accuracy of the method for objective pilling evaluation

is assessed according to results of a comparison of the objective and subjective pilling grades. Therefore estimation of the objective pilling grade follows. Firstly important pill characteristics such as the number, average area of pills and the pilling density were computed from binary images of the samples tested. In the study, an objective pilling grade was estimated from the number of pills N using statistical tests and a linear regression model [17].

$$\begin{aligned} \text{Objective pilling grade} &= \\ &= 4.77 - 0.0143N. \end{aligned} \quad (3)$$

Table 2 displays the pill characteristics computed, the subjective pilling grades and objective pilling grades extracted from binary images of the test fabrics S1 - S5, which were obtained from methods A and B. Pilling was evaluated in approximately the same areas of the samples using methods A and B (5 × 5 cm). The pill characteristics are diverse for each sample because the samples have various pilling grades (the pill size depends on the material as well).

We can compare the results of the test methods according to the subjective and objective pilling grades. It is obvious that the objective pilling grades of the test fabrics obtained from the methods are different in several cases. Probably the most significant difference among the samples tested occurred in the case

Table 2. Comparison of pill characteristics obtained from methods A and B.

Pill characteristics	S1		S2		S3		S4		S5	
	A	B	A	B	A	B	A	B	A	B
Pill number, -	115	61	112	60	244	312	91	111	73	21
Average area of pills, mm ²	0.80	0.45	0.93	0.54	0.92	0.75	0.73	0.56	0.56	0.38
Standard deviation, mm ²	0.31	0.18	0.46	0.26	0.42	0.42	0.40	0.33	0.20	0.09
Pill density, 1/mm ²	0.05	0.02	0.05	0.02	0.1	0.12	0.04	0.04	0.03	0.01
Subjective pilling grade	3		2 - 3		1		3		3 - 4	
Objective pilling grade	3	4	3	4	1	1	3	3	3 - 4	4 - 5

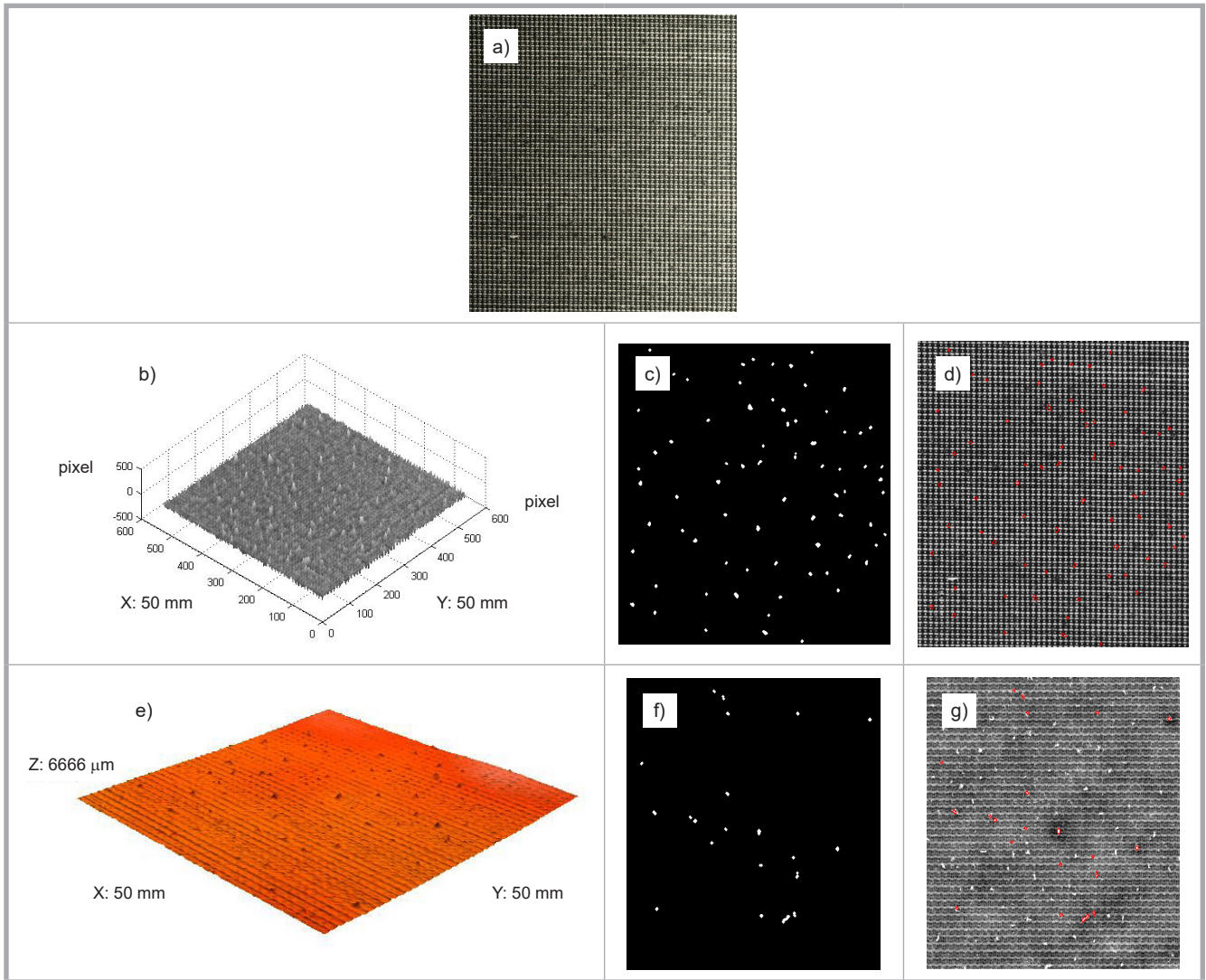


Figure 6. Comparison of results of (a) sample S5 analysed: 3D surfaces, their binary images and grayscale images with detected pills marked by red colour obtained from (b), (c), (d) method A and (e), (f), (g) method B.

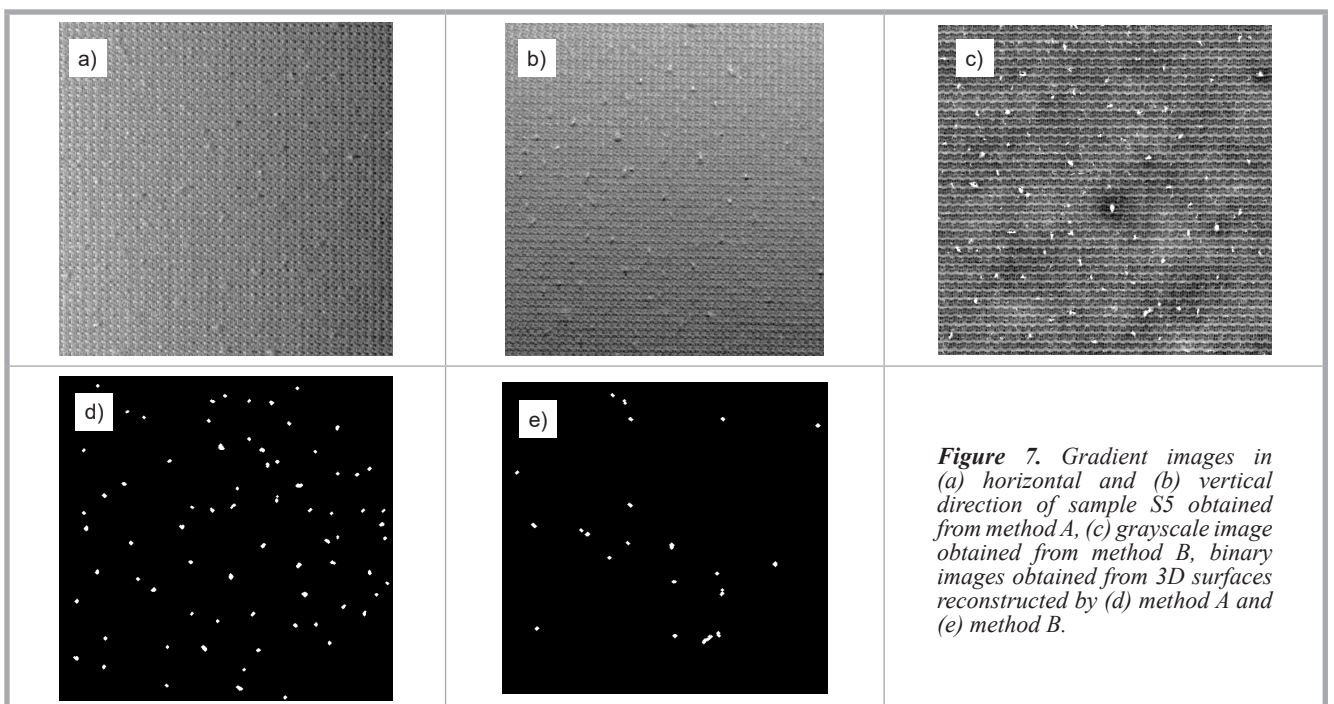


Figure 7. Gradient images in (a) horizontal and (b) vertical direction of sample S5 obtained from method A, (c) grayscale image obtained from method B, binary images obtained from 3D surfaces reconstructed by (d) method A and (e) method B.

of sample S5 (it is obvious from the pill number). It is visible that method A detected approximately three times as many pills as method B. The size of pills was bigger as well (but the pill size is not important for objective pilling evaluation). According to the comparison of the objective and subjective pilling grades, we can see that method A provided more accurate results.

Another possibility of judgment of the methods' accuracy could be a display of gradient images of a sample. In a gradient image, it should be obvious how many pills are there and where they are placed. **Figures 7.a - 7.c** display the gradient images in horizontal and vertical directions obtained from method A and grayscale image obtained from method B, where pills should be clearly visible as well. **Figures 7.d & 7.e** compare the binary images obtained from methods A and method B with respect to the pill distribution and number. From the comparison it is clearly obvious that method A proved to have more accurate results with respect to defect detection than method B.

Conclusion

The study was focused on the testing and comparison of two different principles of 3D surface reconstruction methods. The results were judged according to a comparison of the subjective and objective pilling grades, and to the detection of defects on the top of fabrics (pills). Firstly the gradient field method (method A) was tested. Method A is not time consuming - it needs just a few seconds for 3D surface reconstruction and data processing. Moreover the gradient field method does not require expensive devices. A camera, a planar light source and special algorithm are sufficient for imaging and processing a 3D surface. In contrast to method A, method B was shown as time consuming and not such an accurate tool for pilling evaluation, where a more expensive device was necessary to use for 3D surface reconstruction. Due to the principle of 3D surface reconstruction by method A, pills were more reliable, accurate and faster detected than by method B. For these reasons, the gradient field method could be useful for the objective quality control of garments in the textile industry, especially for the pilling evaluation of various types of fabrics.

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