A novel approach for identification of pills based on the method of Depth from Focus

DOI: 10.35530/IT.069.06.1271

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REZUMAT – ABSTRACT

O abordare nouă pentru identificarea pilingului pe baza metodei Depth From Focus (adâncime de focalizare)

Pentru evaluarea automată a pilingului materialelor textile, informațiile despre adâncimea de focalizare reprezintă una dintre caracteristicile cele mai importante și mai eficiente în extragerea pilingului din imaginea țesăturii. Tehnicile de scanare cu laser sunt adesea folosite pentru a obține imagini 3D cu adâncime de focalizare. Cu toate acestea, din cauza costului ridicat și eficienței scăzute a sistemului de scanare cu laser, cercetatorii au descoperit că tehnica nu este adecvată pentru analiza țesăturilor. Acest studiu prezintă o nouă abordare pentru obținerea imaginii cu adâncime de focalizare folosită pentru a extrage pilingul prin introducerea metodei Depth From Focus (DF). Această abordare captează, în primul rând, o secvență de imagini cu aceeași viziune la diferite poziții de focalizare la microscopul optic automat. Poziția cu cea mai bună focalizare (z) a fiecărui pixel (x, y) a fost determinată prin alegerea stratului de imagine care arată claritatea maximă și s-a format imaginea cu adâncime de focalizare. Acest studiu propune un nou criteriu de evaluare a clarității, care se bazează pe variația gradienților. Ulterior, câteva puncte de bază care indică suprafața de fundal au fost selectate din imaginea cu adâncime de focalizare, iar coordonatele de adâncime (x, y, z) în aceste puncte de bază au fost utilizate pentru a calcula un plan de fundal preconizat. Prin intermediul planului de fundal, a fost extras pilingul deasupra fundalului. O probă de țesătură cu o singură fibră a fost prezentată pentru a ilustra procesul și rezultatul abordării.

Cuvinte-cheie: adâncime de focalizare, detectarea pilingului, evaluarea clarității imaginii

A novel approach for identification of pills based on the method of Depth From Focus

For automatic pilling evaluation of textiles, the depth information is one of the most critical and effective features in extracting pills from fabric image. Laser-scanning techniques are often used for acquiring 3D depth images. However, due to the high-cost and low-efficiency of Laser-scanning system, researchers have found it unsuitable for fabric analysis. This paper illustrates a new approach for acquiring the depth image used to extract pills by introducing the method of Depth From Focus (DFF). This approach firstly captures a sequence of images of the same view at different focal positions under the automatic optical microscope. Then the best-focused position (z) of each pixel (x, y) was determined by choosing the layer of image declaring the max sharpness and formed the depth image. This paper proposed a new sharpness-evaluation criterion which was based on the variance of gradients. Afterwards, a few basic points indicating the background area was selected from the depth image, and then the depth coordinates (x, y, z) at these basic points were used to calculate a predicted background plane. Via the background plane, pills above the background were extracted. A fabric sample with a single fiber upon it was presented to illustrate the process and result of the approach.

Keywords: Depth from Focus, pill detection, sharpness evaluation

INTRODUCTION

Pilling is defined as the entangling of fibers during washing, dry cleaning, testing, or wear to form balls or pills that stand proud of the surface of a fabric [1]. To examine pilling, the fabrics are treated to form typical pills by tumbling, brushing, or rubbing specimens with abrasive materials in a machine and then comparing the processed fabrics with visual standards to determine the degree of pilling on a scale ranging from 1 (very severe pilling) to 5 (no pilling) [2]. Such evaluations are mainly dependent on experts involved and therefore low-efficient and subject.

Testing pilling performance of the fabric has been a problem for a long time. Since image analysis was introduced into fabric-testing industry, pilling evaluation has been made a great improvement. Previous valuable works have made lots of efforts to extract pills on the fabric surface [3]. Many researchers have tried to separate the pills from the background by image threshold [4]. Some researchers performed Fast Fourier Transform (FFT) and wavelet transform [5] to the pilled fabric image with a regular pattern. However, these works encounter with the interference from fabric color and pattern. Laser 3D scanner can acquire the depth information of fabrics to avoid the interference. Due to the high cost and low efficiency of this kind of scanning system, researchers believe that a video camera, together with an effective algorithm to identify pills is still of great research and practical value.

In this paper, we attempt to introduce the concept of depth from focus (DFF) to reconstruct a depth image for pilling analysis. In 1990, E. Ens put forward the concept of depth from focus [6]. Due to the limited depth of field, light microscope can ensure the clearness of the target partly clear while other parts are fuzzy [7]. When the object is in the focus position, it exhibits clearly in the image. Therefore, for the same object, in a series of images captured at different focal positions, the object is clear in one certain image, while fuzzy in other. Therefore, the distance to an object in scene can be deduced by knowledge of current camera positions and the degree that the object is in focus.

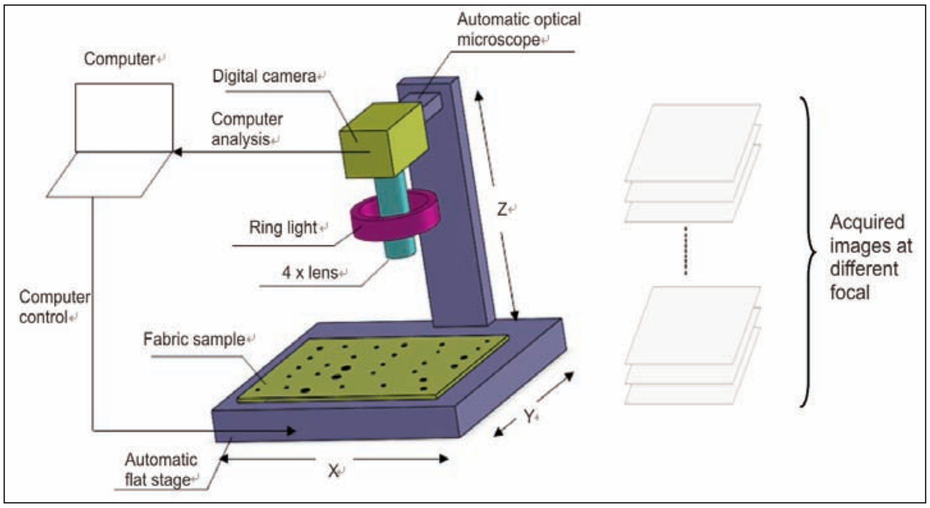


Fig. 1. The Image Acquisition System

The most difficult task of this technique is devising a robust sharpness-evaluation algorithm. The idea of using a sharpness matrix to measure the degree of the in-focus was first proposed by Muller & Buffington, who claimed that a sharpness matrix should produce a global extrema for a focused image [8]. Muller & Buffington proposed three new criteria for automatic focusing: Squared gradient, Laplacian and Signal power. Comparing with common multi-focus object, fabrics exhibit richly-textured features. The in-focus image of the fabric presents more abundant texture than images out-of-focus. According to the characteristics, a novel sharpness-assessment based on gradient variance was introduced in this paper. The gradient variance indicating the contrast of gradients can reflect the texture of the region.

This paper introduced a novel method to extract pills from fabric image based on the theory of DFF. In order to see the fibers in pill balls clearly, the fabric images were captured under the 4×lens by using a optical microscope. A series of images of the same view of fabric was captured at different focal positions. By comparing the sharpness in each layer of image, the depth value of each pixel was determined. Several local background areas were identified based on the depth image and the coordinates (x, y, z) of these area were used as the basic points to simulated the predicted background plane by using the least square method. By using the predicted background plane, the local z-position thresholds can be calculated to extract pills from background according to the depth values.

EXPERIMENTAL WORK

To reconstruct a depth image of the fabric, a sequence of images of the same view of fabric was captured at different focal positions under the optical microscope. A Sharpness-judging algorithm was proposed in this paper to indicate the clearness of each pixel and therefore was used to select the layer of image which declared the best clearness of the pixel. Once the z-positions of all pixels are acquired, the depth information of the fabric can be digitized by using one pixel as the height unit. By analyzing the structural features and spatial distribution of each target type, two threshold values-the degree of altitude differences and number of altitude-jump points-were used to identify fabric surface. The coordinates (x, y, z) of the identified pixels were then used to simulate the predicted fabric surface plane whose coordinates describe the relationship between the surface depth (z-position) and the (x, y) position of the scene. The elevation of each pixel is the distance between the pixel and the predicted fabric plane. Since the fabric surface pixels were on or near the predicted fabric background plane, the fabric surface can be filtered according to the elevation.

Image acquisition

An automatic microscopic equipped with motorized x-y stage to transport the slide was used in this paper. The automatic microscopic system is commonly equipped with a motorized x-y stage to transport the slide and a focusing device to adjust the focal plane of the objective lens. With the optical microscope, the sequential images were recorded with a CCD camera, and the object images were reconstructed in depth image by using DFF method. The fabric sample were magnified by 4×microscope objectives (0.25 NA), by which the fibers of pilling balls can be seen clearly in the captured pilled images. Figure 1 is a diagram of the image analysis system. The hardware used in this work was assembled with simple components. These included a computer, a digital camera, an optical microscopy with motor-controlled stage and a ring-shaped light installed on 4×lenses. The movement of stages was controlled by the computer through a serial port.

Pre-processing of de-noise for original images

Real images containing noise could cause great interference for acquiring depth from focus, due to the fact that noise points present sharp gradient and thus influence measuring sharpness. The median filtering was used in this paper. The 3×3 template window was applied in the median filter. The transform gray level of pixel $T(x, y)$ can be expressed as follows:

$$T(x, y) = median \begin{Bmatrix} G(x-1, y-1), G(x, y-1), G(x+1, y-1), \\ G(x-1, y), G(x, y), G(x+1, y), \\ G(x-1, y+1), G(x, y+1), G(x+1, y+1) \end{Bmatrix} \quad (1)$$

where $G(x, y)$ refers to the gray value of pixel (x, y). The contrast of depth images when median filtering algorithm was processed (figure 2, *b*) and not processed (figure 2, *a*).

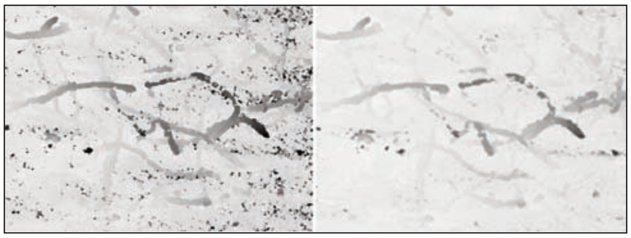


Fig. 2. *a* – The depth image without de-noise processing; *b* – the depth image with de-noise processing

Sharpness-judging algorithm

Many reaches have been studies several section-judging functions. Theses judge algorithms are based on the indicators such as Variance, max frequency and LBP-transformation. However, these algorithms did not work out well in our studies for pills fabrics which exhibit multi-textured and multi-focus phenomenon. When humans observe a texture image, the borders which exhibits high gradient evoke their interests first. The gradients are high on the border of two targets and low in the body of one target. Therefore, the gradients are fluctuant when the image is in-focus. For the de-focused image or the de-focused area of an image, the border between two targets is not conspicuous; resulting in the gradients varies little among the image or the area.

In this paper, a 7×7 sharpness matrix centered with the pixel whose sharpness was to be measured was used to assess the clearness of a certain pixel. Based on the theory above, the sharpness of the matrix was expressed by the variance of the gradient in the area.

The algorithm was realized by following steps:

The first step was to record the gradient of each pixel in the matrix. The gradient was defined as Eq.5. Assuming $P_i(x, y)$ refers to the pixel in i-th layer of images at the pixel coordinate (x, y), and $S_i(x, y)$ is the gradient of $P_i(x, y)$, the following three-dimensional Gradient Matrix (GM) recorded the gradient of each pixel in the $P_i(x, y)$-centered region.

$$GM_i(m,n) = \arg S_i(m,n) \quad (2)$$

The second step was to calculate the sharpness of the matrix. Assuming $C_i(x, y)$, (i =1, 2,…, 41) is the clearness of the $P(x, y)$-centered matrix, and $U_i(x, y)$ is the average gradient value in GM_i, then

$$C_i(x, y) = \sum [GM_i(m, n) - U_i(x, y)]^2 \quad (3)$$

As discussed before, the sharpness of a pixel can be expressed by the sharpness of matrix centralizing in the pixel. We can build the clearness matrix *DCM* in which the sharpness of a pixel can be calculated by Eq.4

$$DCM(i, x, y) = \arg G_i(x, y) \quad (4)$$

Calculating the depth value of each pixel

From figure 3 we can see that the sharpness of a pixel exhibit unimodal distribution. The sharpness reaches a extreme point when the pixel is in-focus at the corresponding layer of image. The depth value of the pixel can be deduced by the lens position where the focused image was captured.

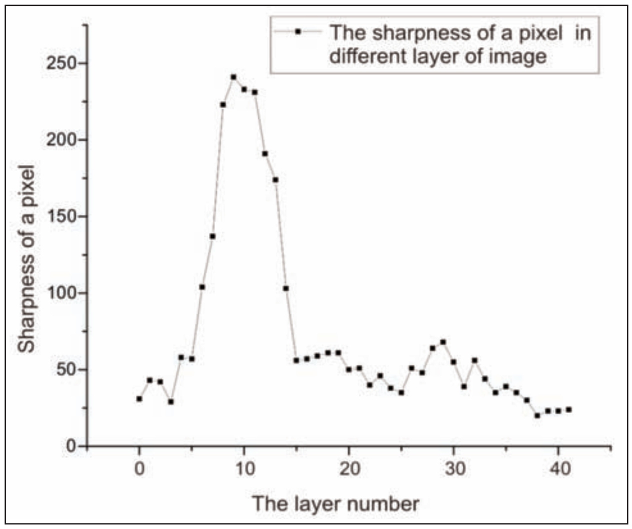


Fig. 3. Sharpness of a pixel in different image layers

Predicting the fabric background plane

After the z-positions of all the pixels were obtained, the depth image was constructed (figure 4). Since the range of gray value is 0 to 255, all the z-positions were normalized to 256 degrees. In the constructed image, pixels with higher intensity of gray value are at a lower depth value.

From the pilled fabric depth image, it was noticed that the pills have a distinct difference with background in depth. Thus, once the depth of the fabric surface background is acknowledged, pixels above the fabric surface can be extracted.

The most difficult part is that the z-position of fabric surface in the area covered by pills is uncertain, due to the interference of the pills. However, the z-positions of fabric surface in these areas could be predicted according to the “flat areas” which were not

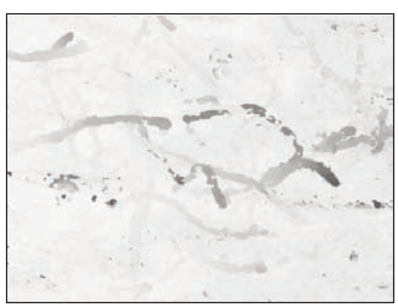


Fig. 4. The depth image

covered by pills. In this step, we utilized the depth coordinates (x, y, z) of “flat areas” to calculate a predicted background plane. The predicted background plane allows the computer to know the z position of the background at any (x, y) position and therefore pixels beyond background can be identified as pills. Figure displays the flowchart of this pill-extraction scheme. The chart of extracting pill pixels is shown in figure 5.

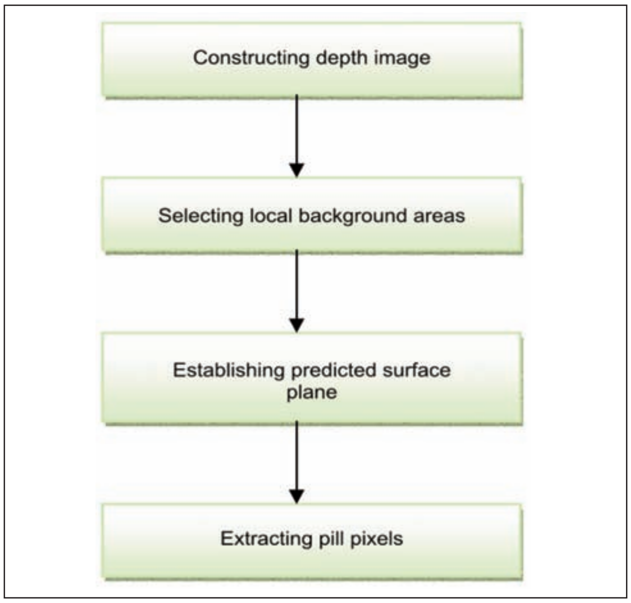
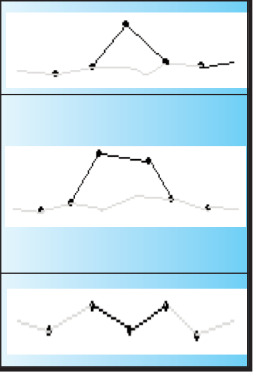


Fig. 5. The chart of extracting pills

Pixels in the depth image belong to one of the three target types: noise, pills and the fabric surface. Pixels on pills are often of high level of depth value while present height difference with proximal pixels. The depth of a noise pixel is isolated with surrounding pixels. Pixels on fabric surface are often of low level of depth value and share similar depth value with nearby pixels. Via analyzing the structural features and the general rules of spatial distribution of the three different target types (noise, pills and background). Table 1 describes and illustrates each target type based on the altitude change information of proximal points.

Table 1



Target type	Description	Diagram
noise	Having major altitude differences with almost all the proximal points	
pills	Having major altitude differences with a majority of proximal points while minor altitude differences with the rest	
back - ground	Having minor altitude differences with almost all the proximal points	

Due to the variant configuration and distribution of pills, the possibility of misjudgment could still exist. Therefore, a small local background area was used instead of a single background point to increase the stability and accuracy of our algorithm. The plane coordinates (x, y) of the local area refers to the coordinates of the central point in area, and the z-position of the background area is the average depth of all points in the area.

Here, a 40×30 window was used to scan the whole image to find a local area without pills. The window moved through the whole image in zigzag from top-left to bottom-right corner. At each stop, a background-judging function was called to determine whether the scanning 40×30 local area is the background area. Figure 6 illustrates the representative pills area and background area. The local areas are remarked by red rectangles and sideward images are enlarged of the red rectangles.

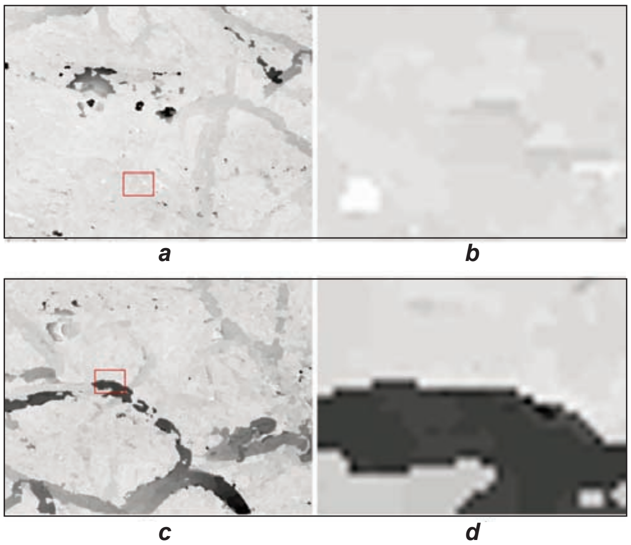


Fig. 6. *a* – An local window of pills; *b* – the enlarged image of the red window in *a*; *c* – an local window of background; *d* – the enlarged image of thered window in *c*

Figure 6, *b* shows the enlarged image of the local background area and figure 6, *d* exhibits the local pills area. We can define the local background area mathematically as follows:

Assuming the scanning 40×30 region is Ω, The flatness of the region (Fl) can be expressed in Eq.6.

$$Ave = \frac{\sum d(x,y)}{N},\ (x,y) \in \Omega \tag{5}$$

$$Fl = \frac{\sum (d(x,y) - Ave)^2}{N},\ (x,y) \in \Omega \tag{6}$$

where $d(x, y)$ is the depth value of the pixel (x, y), and N – the total number of pixels in region Ω.

Here, an experimental threshold values was set for the parameters Fl. If the parameter was under its threshold value, the window can be considered as the flat area”. Figure 7 shows all the identified local background areas in the depth image.

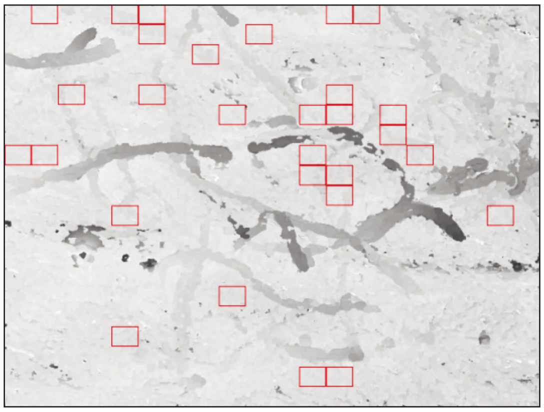


Fig. 7. The identified local background windows

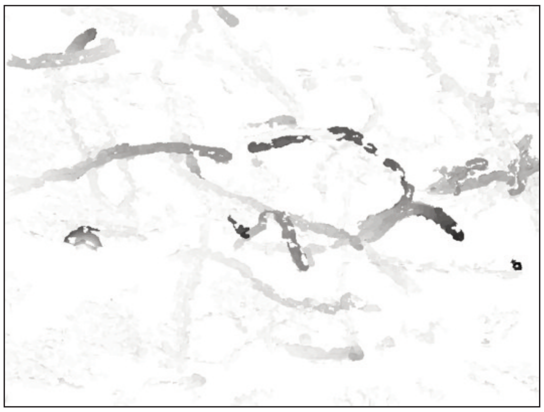


Fig. 8. The identified fuzz and pills

Three-dimensional coordinates (x, y, z) of each local background window were used to predict the background plane by using the least square method.

The background plane is a linear function expressed as

$$z = ax + by + c \tag{7}$$

where z is the depth position, (x, y) are the pixel positions and (a, b, c) are the coefficients.

By using this predicted background plane, the depth value of the background at any positions (x, y) can be determined. Since the real depth value of each pixel (z) was already known according to the depth image, if the depth value (z) is larger than the background depth value (z_b), the pixel (x, y) was identified as the fuzz or pills. The identified fuzz and pills were illustrated in figure 8.

RESULTS

A fabric sample with a single fiber upon it was used to illustrate the step and result of the algorithm. On the image acquisition step, the stage moves along the z-axis as images acquired at different focal positions. In this research, the size of a acquired image is 800×600 pixels with pixel dimensions of 2×2 μm, so the actual fabric area evaluated by this system is 1.6×1.2 mm^2. The total number of layers for the same view is 60, and the step in z-axis is 25 μm. Partly of the acquired images are shown in figure 9.

After the acquisition of the sequential images, the sharpness-evaluation algorithm based on the variance of the gradient was utilized to determine the focused position of each pixel.

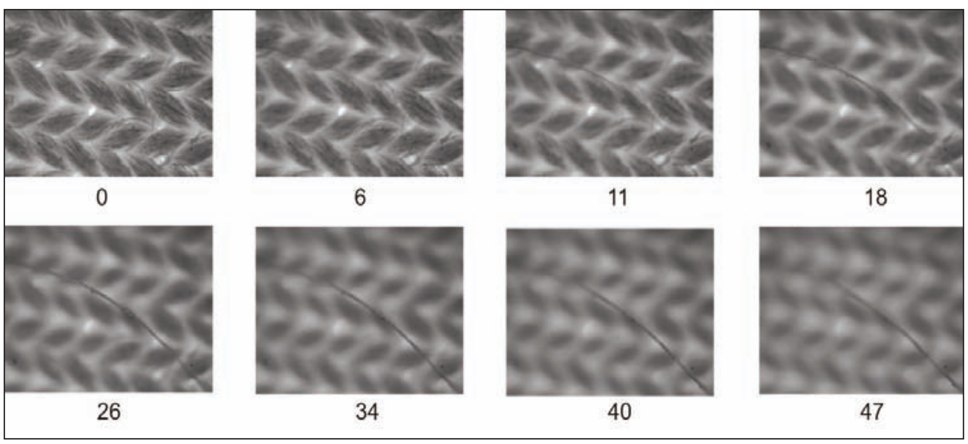


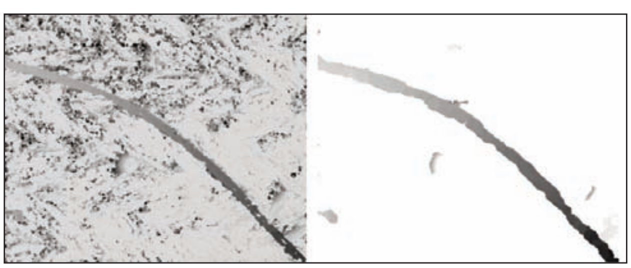
Fig. 9. Partly of the acquired images

Assuming the position where 0-th layer of image was captured as the original point, since the step in z-axis is 25 μm, the depth value (d) of each image can be expressed in Eq.8.

$$d_i = i * 25, \quad i = 0, 1, 2, \ldots, 59 \tag{8}$$

Where i refers to the layer number of the image and the unit of d is μm.

Figure 10, *a* conveys the depth image with identified local background areas. Figure 10, *b* illustrates the extracted pills based on the predicted background plane. From figure 10, *b*, it can be seen that the fiber upon the fabric can be completely extracted with the DFF method. As comparison, this paper presents other three sharpness-evaluation criterion to construct depth image. Three common sharpness-evaluation algorithms: variance, histogram entropy and sum-gradient were used to determine the best-focused positions and construct the depth image. From figure 11, *a*, we could find that the entropy algorithm could identify the texture of the fabric well in the depth image; however



a *b*

Fig. 10. The depth image and the extracted pills

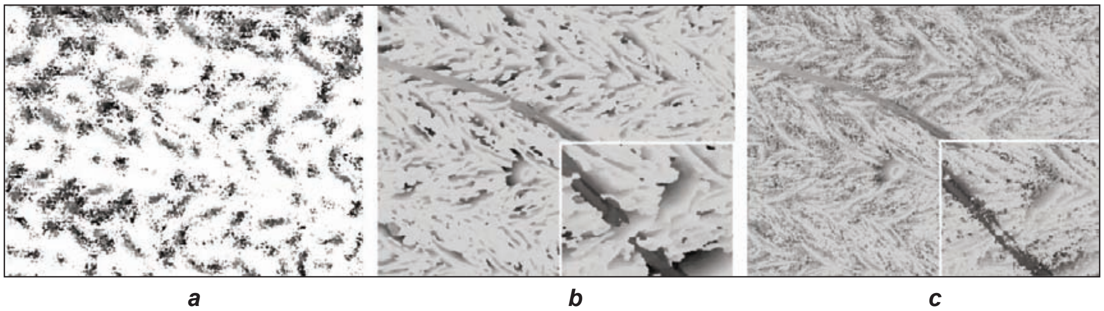


Fig. 11. The depth image with other sharpness-evaluation algorithms

the fiber upon the fabric was missing. Both the variance and the sum-gradient sharpness-evaluation criterion lost parts of the fiber information, as Shown in figure 11, *b* and figure 11, *c*.

CONCLUSION

This work has described the pill identified method based on DFF. This method requires for an automatic microscope, a digital camera and a computer with pill identification algorithm embedded, which is more convenient and much cheaper than Laser-scanning system. With the method of DFF, the best focused position of each pixel can be located and a depth map of the whole image can be estimated. Several local background areas were identified as basic points to calculate a predicted background plane. Pills whose depth values were upon the background were extracted according to the predicted background plane. The sample fabric with a fiber put upon it was used to illustrate the process of this method. By comparing the depth image constructed by other three common sharpness-evaluation criterion, the sharpness-evaluation algorithm based on the variance of the gradients was verified to maintain more complete pill information.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation for the Natural Science Foundation of China (Grant No.61172119), the Program for New Century Excellent Talents in University (Grant No. NCET-12-0825), the Foundation for the Author of National Excellent Doctoral Dissertation of PR China (Grant No. 201168), the Fundamental Research Funds for the Central Universities of China, and the Subsidization Project (14JS039) of Shaanxi Province Education Department Science and Technology Research Plan.

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