Patterned Texture Inspection by The Regular Bands Method

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Abstract

This paper presents a new defect detection method for patterned texture by the Regular Bands (RB) method. Patterned texture, such as patterned fabric, consists of a fundamental repetitive unit. The repetitive unit provides regularity features for every individual patterned texture and characterizes the design of the Regular Bands. A break in regularity is considered to be a defect in the Regular Bands method. The measures of moving average and standard deviation of the pixel intensity are used for defect detection. Defects, such as Broken End and Think Bar, have differential intensity changes compared to the pattern on a repetitive unit of the patterned texture. The Regular Bands method is an effective, fast and shift-invariant approach which can provide clear and clean defect segmentation on patterned fabric. Lots of previous defect detection methods focus on unpatterned (simple) fabric like plain and twill fabrics, while the Regular Bands method contributes to the patterned fabric. The proposed method has been evaluated on box-patterned fabric, with 98.21% detection success rate in a total of 56 defect-free and defective images.

Keywords: Regular Bands, fabric defect detection, regularity analysis, patterned texture

1. Introduction

The research on patterned texture inspection have been increasingly popular among many industries like ceramics, wallpaper and textile industry. The inspection is traditionally operated by factory workers and now changing to be carried out by automatic vision machine system. The aim of inspection is to reduce the manual errors and improve the quality control in the industries. Patterned texture (Fig. 1(a)) is constructed by a fundamental part (Fig. 1(b)), called a repetitive unit [1], which provides regularity feature for analysis in the patterned texture inspection. In this paper, a new defect detection method for patterned fabric using regularity approach is presented. It is named as the Regular Bands (RB) method that is characterized by the concept of moving average and standard deviation.

The main contributions of the Regular Bands (RB) method are:

1. The classical statistical tools, moving average and standard deviation, are newly applied for patterned texture inspection.
2. The Regular Bands (RB) method can handle defects with dark color (low pixel intensities) like Thick Bar, and light color (high pixel intensities) like Hole in the Coin-patterned fabric samples shown in this paper.
3. The RB method has only one parameter called the period length. So, it is not hard to optimize the method for the best detection result. Also, the defective regions can be outlined in the final images very clearly.
4. The defect detection result on box-patterned fabric samples for 30 defect-free and 26 defective images is 98.21%, which outperforms other previous methods.

This paper is organized as follows. Section 2 outlines a brief review of previous approaches for fabric defect detection. Section 3 depicts the mathematical foundation of the Regular Bands and its explicit representation of regularity analysis. The algorithm proposal and defect detection results of the Regular Bands are stated in Section 4. Lastly, the conclusion is drawn in Section 5.

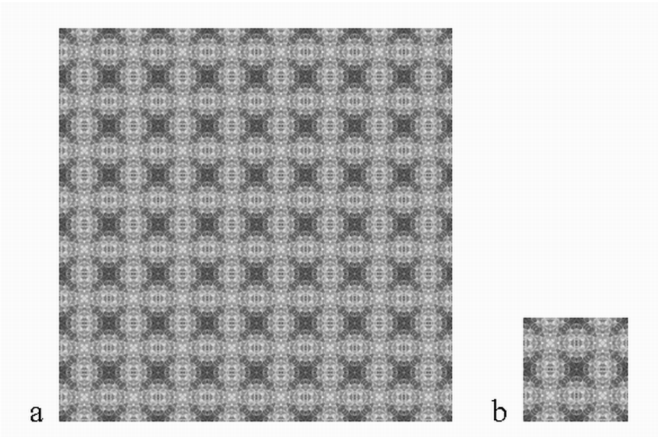

Fig. 1. (a) A sample of patterned texture from Coin-patterned fabric, (b) a repetitive unit of (a).

2. Previous Approaches for Fabric Defect Detection

2.1 Approaches on Unpatterned Fabric

Unpatterned fabric [1] means the kind of the fabrics with little design, e.g., plain and twill fabrics. There are numerous methods developed for unpatterned fabric. A popular approach is using spectral approach like Fourier transform [2], Gabor transform [3], and wavelet transform [4]. Fourier transform converts the information from time domain into frequency domain, especially specialized to present for directionality of line patterns. So, the Fourier approach in Ref. [2] identifies the defects as irregularity in the frequency spectrum. On the other hand, Gabor and wavelet filters give spatial-frequency analysis to localize the defects, where Fourier bases do not have spatial domain support. Both Gabor and wavelet approaches can give out multi-scale and multi-orientation images in order to help in reducing data size, but they are computation intensive. The Gabor approach [3] combines Gabor and wavelet features for twill fabric inspection. However, not all defects can be detected. The standard wavelet basis is not useful for capturing the most distinguishable features of all kind of defects, so [4] proposes an adaptive wavelet filters design for twill fabric defect detection.

2.2 Approaches on Patterned Fabric

The research on Patterned fabric inspection are relatively little compared to that of unpatterned fabric. In literature survey, there are several methods have been developed for the patterned fabric defect detection, namely as the traditional image subtraction (TIS) method, the Hash function method, wavelet golden image subtraction (WGIS) method, the direct thresholding (DT) method and the co-occurrence matrix method.

The traditional image subtraction method [5] proposes to use a golden image (reference image) to have an EXCLUSIVE-OR operation with every test image in order to segment out the defective regions on Lace, one kind of patterned fabric. However, an accurate pixel-by-pixel comparison between golden image and test image is hard to achieve.

The Hash function method [6] is emerged from the idea of data encryption and decryption in cryptography. Four basic types of Hash functions with offset properties, used in patterned fabric defect detection, are checksum, plain, XOR and multiplication functions for input textures. A defective part appears as an outstanding irregularity which can be thresholded out of the defect-free parts in the signatures of the Hash functions. The choice of Hash functions is depended on the pattern complexity of patterned texture. The Hash function is a one-dimensional approach and saving in computation. But, the TIS and Hash methods are not effective because they are very sensitive to noise and alignment.

The wavelet golden image subtraction method [1] firstly applies Haar wavelet transform as a smoothing filter to remove excessive noises on the input dot-patterned fabric images. A matrix of the energy of the golden image subtraction (GIS) is calculated between a golden image (an image with one repetitive unit at least from the patterned texture) and every test image extracted from an input image. After threholding on every image of the energy of GIS, the WGIS method enables to outline the defective regions. But, the WGIS method is computation demanding due to the sliding process of the golden image on the input image.

The direct thresholding method [1] utilizes the fourth level of horizontal and vertical detailed sub-images of every Haar wavelet transformed input image. A step of thresholding is achieved on those sub-images directly since any defective regions are substantially enhanced in the detailed sub-images. The DT method is computation fast, but the final output images are coarse in resolution.

The co-occurrence matrix method [7] applies gray relational analysis with the co-occurrence matrices, which characterize the spatial properties of patterned fabric using grey level spatial dependence on patterned fabric. The co-occurrence matrices can measure many properties of patterned textures like uniformity of energy, correlation, maximum probability, inertia, homogeneity and so on. The weaknesses of the CM method are too sensitive to small variations of patterned texture and intensive computation.

3. Mathematics of Regular Bands

The Regular Bands method makes use of the regularity feature, periodicity, of patterned texture. The periodicity is traditionally defined as a repeat distance of a repetitive unit of a patterned texture, or spatial relationship between designated pixels. The RB method has a new presentation of the periodicity by using a transformation of defect-free part, in one-dimensional view, into a new regular signal. Any irregularity of the transformed signal is considered to be defective. The preprocessing step, definitions, brief discussion and algorithmic steps of the RB method are described as below.

3.1 A Preprocessing Step

A transformation for every input image is carried out before passing through the main procedure of the Regular Bands method. Suppose f defect-free images are of size $p \times q$, $Y_k = (y_{ij}{}^k)$ where $k = 1,\ldots,f$, $i = 1,\ldots,p$ and $j = 1,\ldots,q$. There is a mean value, $y_k = mean(y_{ij}{}^k)$, corresponding to every defect-free sample. By collecting of f mean values of all y_k, the overall average of them is { $\bar{y} = mean(y_k)$ }.

A transformed database is obtained, i.e. $X_k = (\bar{x}_{ij}{}^k - \bar{y}) = (x_{ij}{}^k)$, $x_{ij} \in [0 - \bar{y}, 1 - \bar{y}]$ where $\bar{X}_t = (\bar{x}_{ij}{}^t)$, $t = 1,\ldots,h$, is the set of h input images.

3.2 Definitions of Regular Bands

Suppose $F = f(a,b)$ is a transformed image of size $p \times q$. For a particular row in the image after the preprocessing step,

Light Regular Band (LRB) is defined as:

$$L_{r_n} = |\, u_{r_n} - \sigma_{r_n} | + u_{r_n} \quad (1),$$

Dark Regular Band (DRB) is defined as:

$$D_{r_n} = |\, u_{r_n} + \sigma_{r_n} | - u_{r_n} \quad (2),$$

where the *Moving average* u_{r_n} *is defined as:*

$$u_{r_n} = \left(\sum_{b=r_1}^{r_n} f(a,b) \right) / n \quad (3),$$

Standard deviation is defined as:

$$\sigma_{r_n} = \sqrt{ [\sum_{j=r_1}^{r_n} (f(a,b) - u_{r_n})^2] / n } \quad (4),$$

where n is an integer value denoting one period length of the repetitive unit and, $f(a,b)$ is the pixel value at row a and column b of the image F, the summation is from r_1 th pixel to r_n th pixel with $1 \le r_1 \le r_n \le q$, $r_1 \in [1, q-n]$, $r_n \in [1+n, q]$ and $L_{r_n}, D_{r_n}, u_{r_n} \in R$.

In [8], we also show $L_{r_n} > 0$ and $D_{r_n} > 0$.

3.3 Brief Discussion of Regular Bands

A. How Regular Bands Works

Fig. 2 shows how the DRB works on one defect-free and one defective samples of the Coin-patterned fabric of size 680×680. The value for n is 85 which is the period length (repeat distance) for both the row and column of a repetitive unit of the Coin-patterned fabric.

The defect-free and defective samples (Fig. 2(e),(f)) are transformed as two matrices after calculating the DRB on columns. For every column, the DRB forms a regular (defect-free) signal (Fig. 2(c)) which is useful for defect detection. The range of that signal can be utilized to segment out any values exceeding the boundaries. Any irregularity of defective part (Fig. 2(d)) is believed to exceed that range of the regular signal. By thresholding, the defective region can be outlined.

The LRB is designed to specialize in detecting the light defects like the Broken End sample of the Box-patterned fabric in Fig. 3(a) while the DRB is for dark defects like Thin Bar of the Dot-patterned fabric in Fig. 3(b). There exists a mathematical principle founding for the Regular Bands, which is explained in Ref. [8].

By the algorithmic steps outlined in Fig. 4, either LRB or DRB works on rows and columns as a whole for the first step. Then, the thresholded results of both rows and columns are combined for each band by an OR-operation. Lastly, one more OR-operation is used to combine the thresholded results of the LRB and the DRB. The detection results of two samples from the Coin-patterned fabric are shown in Fig. 5.

B. The Need of Preprocessing Step of Shifting by Mean

Fig. 3 shows how LRB and DRB work under the down-shifting by mean on the mathematical design.

(B1) How LRB Works

According to the Broken End sample of Box-patterned fabric, the values of LRB on 88th row always exceed the threshold of the range of the regular (defect-free) signal of LRB under the condition of non-shifted preprocessing in the first plot in Fig. 3(c).

Mathematically, $L_{r_n} = 2 \cdot u_{r_n} - \sigma_{r_n}$ since $u_{r_n} \geq 0$ and $\sigma_{r_n} \geq 0$ [8]. The detection is always false positive at the defect-free region. However, by down-shifted preprocessing, LRB can deal with two situations, i.e., if $|u_{r_n}| \leq \sigma_{r_n}$, $L_{r_n} = \sigma_{r_n}$, otherwise $L_{r_n} = 2 \cdot u_{r_n} - \sigma_{r_n}$. The 2nd plot of

Fig. 3(c) depicts how LRB works at the designated approach.

(B2) How DRB Works

In the first plot of Fig. 3(d), the first figure shows a result without a down-shifted preprocessing. The values of DRB on 218th row of Thin Bar sample of Dot-patterned fabric always are bounded by the threshold of range of regular (defect-free) signal of DRB.

From [8], as $D_{r_n} = \sigma_{r_n}$ in such case, the detection is false negative for the defective region. But, after the down-shifted preprocessing, DRB can manage two situations, i.e., if $|u_{r_n}| \leq \sigma_{r_n}$, $L_{r_n} = \sigma_{r_n}$, otherwise $D_{r_n} = 2 \cdot u_{r_n} - \sigma_{r_n}$. A satisfied detection is achieved in the 2nd plot of Fig. 3(c).

Therefore, there is a need to have a preprocessing step of down-shifting for every input image in the RB method.

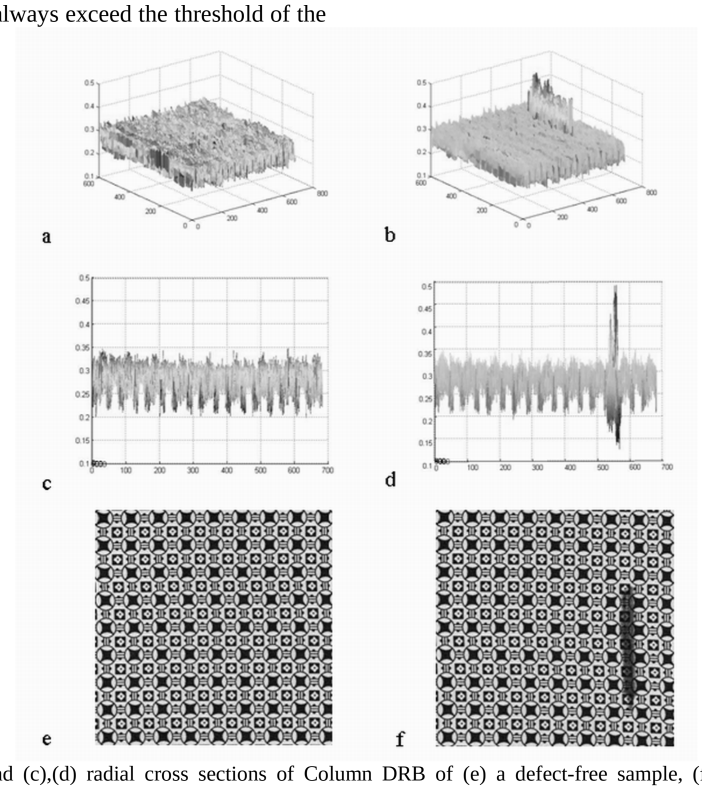

Fig. 2. (a),(b) Perspective plots and (c),(d) radial cross sections of Column DRB of (e) a defect-free sample, (f) a defective Thick Bar sample on Coin-patterned fabric respectively.

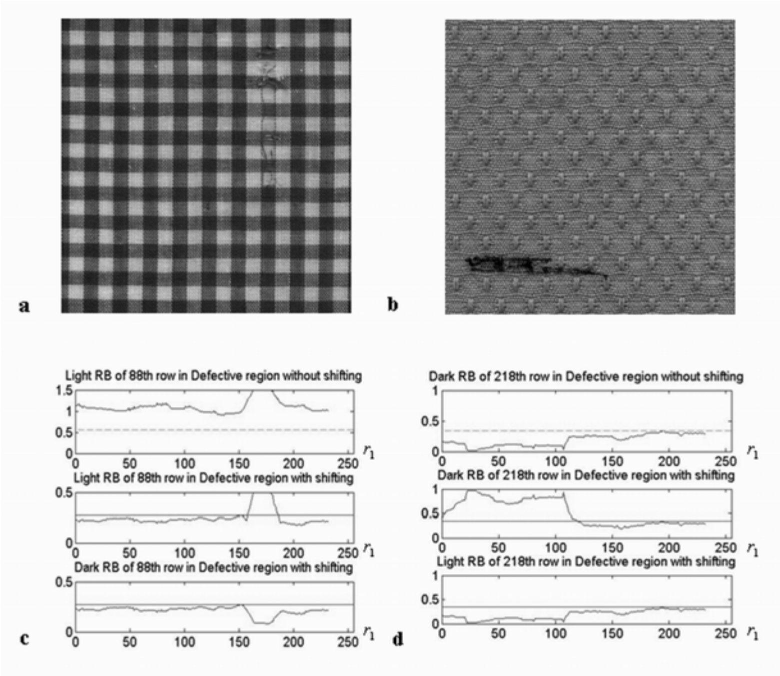

Fig. 3. Two defective samples, (a) Box-patterned fabric and (b) Dot-patterned fabric. (c) A 88th row of Box-patterned and (d) a 218th row of Dot-patterned with passing through LRB and DRB, respectively, using Non-shifting and shifting as preprocessing step of detection, $r_1 \in [1, q-n]$. (Dashed lines are marking the threshold value of upper bound of the range of regular signal WITHOUT shifting in preprocessing step. Lines are marking the threshold value of upper bound of the range of regular signal WITH shifting in preprocessing step.)

4. Evaluation of The Regular Bands Method

4.1 Algorithmic Steps of The Regular Bands Method

Fig. 4 outlines the procedures of the Regular Bands method in our methodology. In brief, the Regular Bands method is divided in two stages, a training stage and a testing stage (Fig. 4).

A. The Training Stage

1. Input histogram equalized defect-free images of a patterned fabric database.
2. Calculate the mean values of all pixel values of input images. Perform a shifting of mean for all input images.
3. Calculate the Regular Bands, including Dark Regular Bands and Light Regular Bands, on rows and columns respectively. Totally, four Regular Bands are obtained, i.e. *DRB on rows, DRB on columns, LRB on rows and LRB on columns.*
4. A set of threshold values is obtained from the maximum and minimum of the matrices of one Regular Band on rows or columns. Totally, four sets of threshold values are obtained, i.e. *DRB on rows, DRB on columns, LRB on rows and LRB on columns.*

B. The Testing Stage

1. Input histogram equalized test images of a patterned fabric database.
2. Perform Steps 2 to 3 as the training stage.
3. Threshold the four Regular Bands (*DRB on rows, DRB on columns, LRB on rows and LRB on columns*)
4. Zero padding on every threholded matrices and have an OR-operation for LRB between rows and columns. Then, have the same process for DRB between rows and columns.
5. Have an OR-operation between the zero padded matrices between LRB and DRB.

4.2 Defect Detection Results 2 Typical Examples of Coin-patterned Fabric

In this paper, two typical examples of defects on a patterned texture, Coin-patterned fabric, are used in the evaluation. A Thick Bar sample is one kind of defects with dark defect, oil stain, sticking on the surface of patterned fabric. A Hole is another kind of defects with light defect, breaking yarns in some regions, happening on the fabric.

The Coin-patterned samples are size of 680×680, with a period length, 85, on both rows and columns of its repetitive unit. Fig. 5 shows the defect detection result of a Thick Bar and a Hole from the database. The RB method can successfully tackle these two typical examples of dark and light defects. Moreover, the RB method can outline the defective regions visually. The final images are crystal clear and clean with no excessive noise.

4.3 Defect Detection Results on Box-patterned Fabric

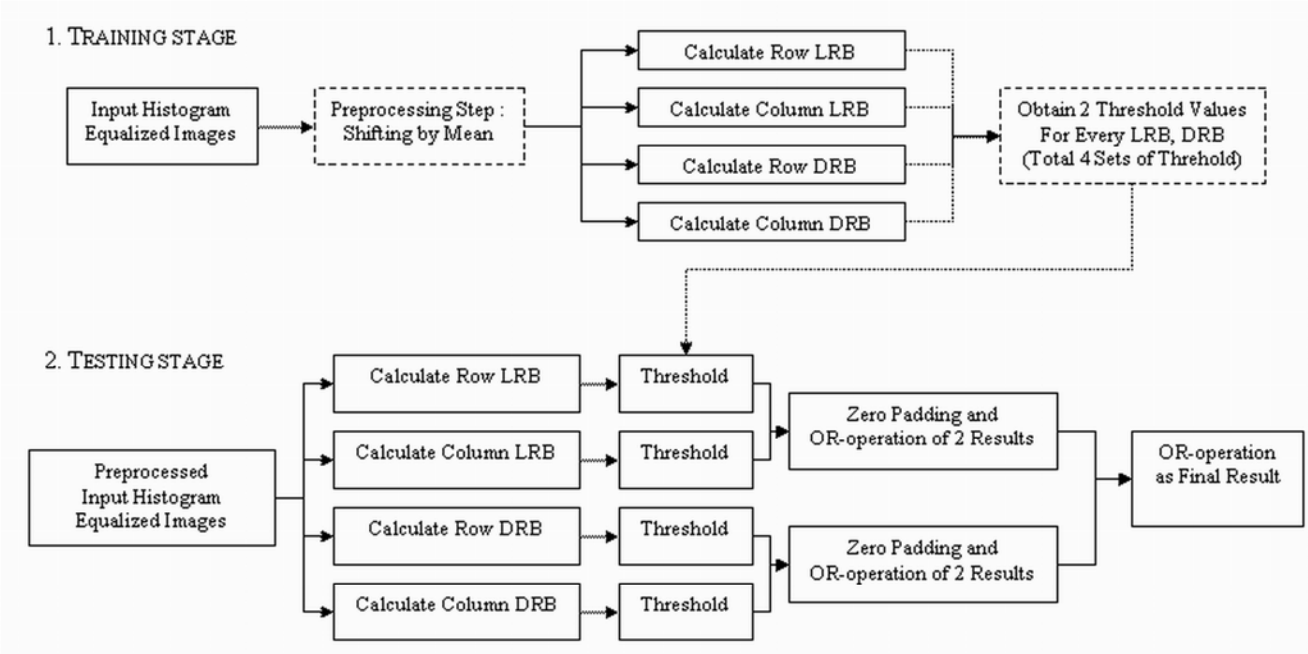

Fig. 4. Stages of the Regular Bands Method.

A more extensive evaluation is carried out using a Blue Box-patterned fabric database in this paper. Table I outlines the defect detection result of the Regular Bands method on the samples of Box-patterned fabric. A total of 55 images, with 30 defect-free and 26 defective images of size of 256×256 (65,536 pixels), is in the database. The database stores five kinds of defects, namely as Broken End, Hole, Netting Multiple, Thick Bar and Thin Bar. The period length, *n*, is set as 25, for both rows and columns of a repetitive unit, in the calculation of Regular Bands. A threshold image is of size 232×232 (53,824 pixels). The defective regions represent as white pixels after thresholding in the RB method. In the training stage of Box-patterned defect-free samples, the maximum number of white pixels is 111 so that the threshold value for this kind of fabric is set as 120. The detection success rate of 26 defective images is 100% while that of 30 defect-free images is 96.15% (only 1 out of 30 failed).

5. Conclusion

The Regular Bands method introduced in this paper is an effective and robust method for patterned fabric defect detection. The RB method is developed with the concept of regularity and it has several advantages compared with the previous approaches. First, it is based on the classical statistical ideas, moving average and standard deviation, in order to maintain simplicity for application. Only one parameter, the period length, is used throughout the methodology. Secondly, it is shift-invariant for the calculation of the Regular Bands on the repetitive units of a pattern fabric, and sensitive to the small changes on them. Thirdly, the final image is crystal clear and clean without excessive noise, and enables us to outline the defective regions. The RB method is fast and effective on defect detection for patterned fabric so that it can be facilitated on an on-loom machine. The detection results can be utilized for defect classification in future research. As a conclusion, not only the RB method is beneficial for the textile industry, but it also contributes to the quality improvement in the ceramics and wallpaper industries.

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TABLE I
STATISTICAL DETECTION RESULTS OF BLUE BOX-PATTERNED FABRIC

Different Kinds of Defective Images	Number of White Pixels in Final Threshold Images n=25 in RB on Row and Column	
	Number of Images	Mean
Broken End	5	1064.2
Hole	5	132
Netting Multiple	5	278.8
Thick Bar	6	1994
Thin Bar	5	488.2
Defect-free	30	43.43

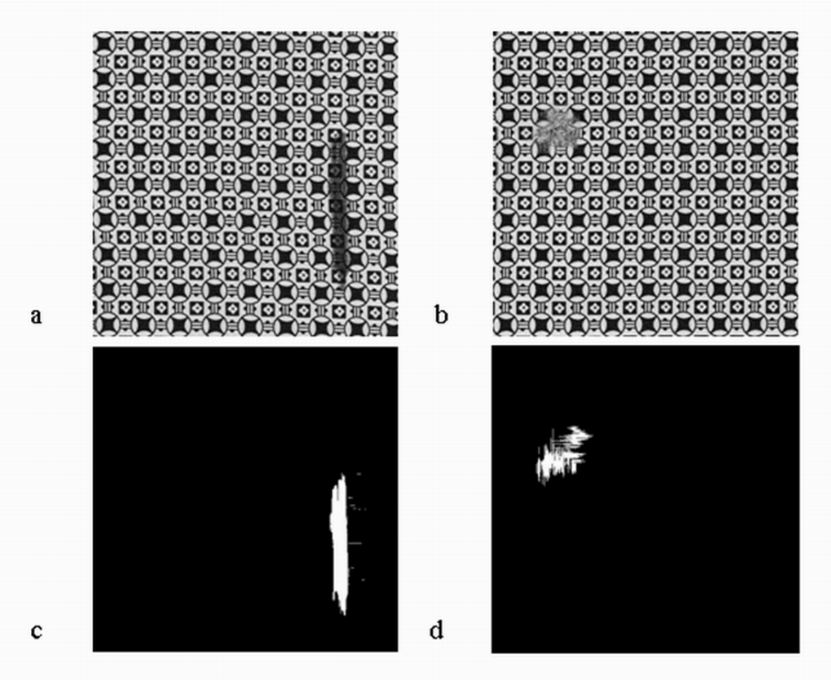

Fig. 5. (a) Thick Bar sample, (b) Hole sample of Coin-patterned Fabrics, (c) and (d) detection result of (a) and (b), respectively, after the RB method.