INSPECTION OF DEFECTS IN FABRICS USING GABOR WAVELETS AND PRINCIPLE COMPONENT ANALYSIS

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ABSTRACT

In this paper, a new method for inspection of textile defects in fabrics is presented. The method is based upon the extraction of features by Gabor wavelets. The Gabor wavelets transform provides an effective way to analyze images and extract features of textures. Principal component analysis using singular value decomposition is used to reduce the dimension of feature vectors. Performance of the method has been tested with defective fabric images taken from TILDA textile texture database. Experiments show that these defects are detected accurately.

1. INTRODUCTION

Nowadays quality control after manufacturing has been a quite important factor in the textile industry. Defect detection is mostly fulfilled by human quality control inspectors in the traditional textile industry. Sari-Sarraf and Goddard [1] showed that only about 70\% of the defects could be detected by the most highly trained inspectors. A product price is adjusted according to frequency and types of fabric defects. Effects causing fabric faults can be got rid of by revising of a production stage together with information of fabric faults and production efficiency can be improved. After the recent improvements in computer technology, this process is now being replaced by automatic inspection systems that employ image processing techniques.

In digital images, noise is distributed nonuniformly in the spatial domain as it is uniformly in frequency domain [2]. Characteristics of frequency domain are generally better than spatial-domain characteristics regarding noise sensitivity. Major examples of frequency domain approaches are Wavelet, Gabor and Fourier transforms, which are used for texture feature extraction [3-9]. Twenty-eight textural features in the Fourier spectrum are used for texture analysis by Liu and Jernigan [2]. The Fourier analysis is used for fabric inspection by Chan and Pang [8] too.

Recently, Wavelet transform based multi-resolution decomposition techniques are also used for feature extraction. An image can be decomposed hierarchically into subimages at different spatial frequencies with this technique [11]. Wavelet transform decomposes an image into a lowpass (approximate) subimage and a group of highpass (detail) subimages on two-dimensional frequency spectrum. These subimages, which were decomposed into various resolutions and various frequencies, give information about textural features of main image. A wavelet transform that is structured as tree is suggested by Chen and Kuo for a texture classification [12]. Entropy and energy metrics of decomposed wavelet packets are used as textural features by Fan [13].

The multichannel Gabor filters have been preferred in the last decade because of its characteristics which allow to analyze textured images with special orientation and frequency in both spatial and spatial frequency domains [5,8]. The textured image is filtered with Gabor filter banks, which can be characterized by a window function scale, a frequency and an orientation of the flat sinusoid wave; and textural features is found out by this way. Various uses of Gabor filters in texture analysis are utilized by Clausi and Jernigan [10]. Gabor Wavelets are used in many computer vision applications such as texture classification, analysis of mammograms, document image segmentation, tongue image recognition, identification of bivalve larvae [21-25].

In this paper, Gabor wavelets and principal component analysis are used for detection of textile defects in fabrics. Features of fabric images are extracted by Gabor wavelets. The Gabor wavelets transform provides an effective way to analyze images and extract features of textures. Principal component analysis using singular value decomposition is used to reduce the dimension of feature vectors. Performance of the proposed method has been tested with various defective fabric images. Experiments show that these defective areas on fabric are detected accurately.

2. GABOR WAVELETS

The Gabor wavelets, which provide an effective way to analyze images, are inspired by the orientation and spatial frequency selective properties of simple cortical neurons. Gabor wavelets are widely used in segmentation, texture analysis and computer vision applications [14-19].

Let $I(z)$ be the gray level distribution of the input image. Gabor wavelets transform on $I(z)$ can be written as a convolution of $I(z)$ with a family of kernels $\psi_i$:

$\hat{O}_i(z) = \overline{I(z)} \ast \psi_i(z)$

where $\hat{O}_i(z)$ is the convolution result at $k$. The Gabor wavelets (kernels) take the form of a plane wave restricted by a Gaussian envelope function [18, 20]:

$\psi_i(z) = \frac{1}{\sigma^2} e^{-\frac{(z - k)^2}{2\sigma^2}} e^{i \pi k^2}$

where $k$ determines the wavelength and orientation of the kernel $\psi_i(z)$ in image coordinates. The first term in bracket is the oscillation part, and the second is the DC part.
The parameter $k$ is defined as $k(\mu, \nu) = k_\mu e^{i \phi}$, where $\mu$ and $\nu$ are the orientation and scale of the Gabor kernels, $k_\mu = k_\nu \alpha x / f''$ and $\phi_\mu = \pi \mu / 8 k_{max}$ is the maximum frequency, and $f$ is the spacing factor between kernels in the frequency domain.

The $\psi(z)$ form a family that is self-similar under the application of the group of translations, rotations, and resizes. The effect of the DC term becomes negligible when the parameter, determining the ratio of the Gaussian window width to wavelength has sufficiently large value.

Figure 1, shows the even and odd parts of the Gabor Wavelet (kernel).

By applying the convolution theorem, the Gabor wavelets transform on an image can be derived via the fast Fourier transform (FFT)

$$
\mathcal{F}\{O(z)\} = \mathcal{F}\{I(z)\}\mathcal{F}\{\psi(z)\}
$$

In this paper, distinctive features of fabric features are extracted by Gabor wavelets.

### 3. PRINCIPLE COMPONENT ANALYSIS

Principal Component Analysis (PCA), which is also known as the Hotelling Transform or the Karhunen-Loève Transform, is a widely used method in signal processing [26]. The fundamental idea in PCA is to find the components so that they explain the maximum amount of variance possible by some linear transformed components. PCA is a powerful analysis technique used to reduce the dimension of the data. PCA is explained briefly as follows:

Let $X$ be the data

$$X = [x_1, x_2, \ldots, x_n]$$

where $n$ is the amount of data samples, $x_i$ is the $i$th data sample of dimension $d$. First of all, $\bar{X}$ mean value of $X$ is calculated, then $\bar{X}$ subtracted from the data and difference matrix $\bar{X}$ is calculated by

$$\bar{X} = [x_1 - \bar{X}, x_2 - \bar{X}, \ldots, x_n - \bar{X}]$$

The covariance matrix $C$ is calculated by

$$C = \frac{1}{n} \bar{X}\bar{X}^T$$

Eigen vectors $\Phi_\lambda$ and eigen values $\Lambda_\lambda$ of the covariance matrix are calculated by

$$C\Phi_\lambda = \Phi_\lambda \Lambda_\lambda$$

where

$$\Lambda_\lambda = \begin{bmatrix}
\lambda_1 & 0 & \cdots & 0 \\
0 & \lambda_2 & \ddots & \vdots \\
\vdots & \ddots & \ddots & 0 \\
0 & \cdots & 0 & \lambda_m
\end{bmatrix}$$

is the diagonal matrix of eigen values corresponding to the eigen vectors of

$$\Phi_\lambda = [\phi_1, \phi_2, \ldots, \phi_m]$$

$m$ eigen vectors which correspond to the higher eigen values are selected and projection matrix $W$ (which is $d \times m$) is obtained.

$x_i$ (is $d$ dimension) can be reduced to $x'_i$ by

$$x'_i = W^T(x_i - \bar{X})$$

However, calculation of covariance matrix takes long time for higher dimension data and eigen value decomposition is possible for only square matrix. Therefore, in this paper, singular value decomposition (SVD) is utilized for calculation of projection matrix.

### 4. METHOD

In this paper, experiments are executed by using defect-free and defective fabric images taken from TILDA Texture Database. A total of eight representative textile kinds were included in the database. Based on the analysis of textile atlases, seven error classes were defined. With the reference classification -a class of textiles without error- there exists therefore eight sorts of classes for each kind of textile [27].

In this method, firstly, feature sets are obtained by using defect-free fabric images. Let $X$ be the number of windows taken from images, size of windows is $N \times N$. Distinctive features of windows are extracted by using Gabor Wavelets of three scales $\nu \in \{0,1,2\}$, eight orientations $\mu \in \{0, \ldots, 7\}$, $\sigma = 2\pi$, $k_{max} = \pi / 2$ and $f = \sqrt{2}$. Obtained features are reduced to $m$ dimension by using PCA.
In the defect inspection step, 24 Gabor Wavelets are applied on $N \times N$ sized windows consecutively taken from test images. These feature vectors are reduced to $m$ dimension by using PCA. Then, every feature vector is compared with feature set of defect-free images, and every feature vector of test image is classified by using rule-based method. In comparison step, norm-1 (Manhattan norm) of difference vector is compared with definite error threshold. In the step of determining of error threshold, mean value of feature set of defect-free images is calculated, and subtraction of every feature from the mean value is obtained. The thresholding value is obtained by multiplying norm-1 of difference vector by coefficient which is determined by fabric types.

5. RESULTS

In this paper, inspection of fabric defects is executed by using Gabor Wavelets and Principle Component Analysis. Distinctive features of fabric are extracted by Gabor wavelets. Principal component analysis using singular value decomposition is used to reduce the dimension of feature vectors. The method obtains defected areas on fabrics by using features that are extracted from defect-free images. A method algorithm is developed by using Intel IPP (Integrated Performance Primitive) and Intel MKL (Math Kernel Library) on Visual C++ platform.

In this paper, 768x512 sized images are used and 16x16 sized windows ($N = 16$) are taken from these images. The feature vector (6144 sized) extracted from every window by means of Gabor Wavelets and a dimension of feature vectors are reduced to $m = 128$ by using PCA.

The performance of the proposed method has been tested with two different fabric types such as c1r1 and c1r3 (from c1 fabric type) taken from TILDA textile texture database. A total of 400 images including 4 defect types (e1–e4) are used. Inspection results are shown in Table-1 and Figure-2. In Table-1, e0 presents defect-free images, e1–e4 presents 4 various defect types. The first row of the Table-1 represents number of windows taken from e0 defect-free images and a dimension of feature vectors are reduced to $m = 128$ by using PCA.

<table>
<thead>
<tr>
<th></th>
<th>c1r1 (TC=2.0)</th>
<th>c1r3 (TC=2.5)</th>
<th>Success (%)</th>
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<tr>
<td>e0</td>
<td>4800/6</td>
<td>4800/13</td>
<td>99.8</td>
</tr>
<tr>
<td>e1</td>
<td>58/1</td>
<td>52/0</td>
<td>99.1</td>
</tr>
<tr>
<td>e2</td>
<td>56/13</td>
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<td>79.5</td>
</tr>
<tr>
<td>e3</td>
<td>76/9</td>
<td>70/6</td>
<td>89.7</td>
</tr>
<tr>
<td>e4</td>
<td>52/8</td>
<td>76/31</td>
<td>69.5</td>
</tr>
</tbody>
</table>

Table 1. Inspection results.

The performance of the method has been tested with defective fabric images taken from TILDA textile texture database. Experiments show that these defects are detected accurately. The method operates successfully for such defects as hole, cutting, ripped (e1) and thread errors (e3). However, the performance of method is less for such indistinct defects as oil spots (e2) and as objects on surface (e4). Indistinct defects can be more visible by way of regular and effective illumination of fabric and inspection performance can be better for these kind of defects.
ACKNOWLEDGEMENT

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REFERENCES