TEXTURE DEFECT DETECTION USING THE ADAPTIVE TWO-DIMENSIONAL LATTICE FILTER*

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ABSTRACT

In this paper, the eight parameter two-dimensional adaptive lattice filter is used to detect defects in textures corresponding to raw textile fabrics. A novel histogram modification technique is also applied for pre-processing the grey level texture image. Moreover, with the proposed scheme, it is possible to detect defects using the defective image only.

1. Introduction

Quality is a topical issue in manufacturing, designed to ensure that defective products are not allowed to reach the customer. Machine vision is an important technology resulting in accurate and inexpensive quality control equipment. Since in many areas, the quality of a surface is best characterised by its texture, texture analysis plays an important role in automatic visual inspection of surfaces. There has been a limited number of applications of texture processing to inspection problems. Erçil et.al. [4] proposed a model based technique to detect and locate the various kinds of defects that might be present in a given painted surface. Jain et.al. [5] used the texture features computed from a bank of Gabor filters to automatically classify the uniformity of painted metallic surfaces. Chen and Jain et.al. [1] used a structural approach to defect detection in textured images. Conners et.al. [2] utilised texture analysis methods to detect defects in lumber wood automatically. Siew et.al. [6] proposed a method for the assessment of carpet wear. Dewaele et.al. [3] used signal processing methods to detect point and line defects in texture images.

In [9], a 2-D filter structure was derived by applying the adaptation algorithm developed by Moro et.al. [7] to the eight-parameter 2-D lattice filter structure [8]. The filter is used to perform forward prediction on the texture image, for removing the predictable part in the image which is the texture. That remains afterwards will be the prediction error that is expected to correspond to the defects. In order to increase the effectiveness of this approach, a novel histogram modification technique has also been used before the forward prediction error filtering.

2. The Eight Parameter 2-D Lattice Filter

The eight parameter 2-D lattice filter structure [9] consists of concatenated nine-input nine-output stages that are defined in terms of the reflection coefficients.

The inputs and the outputs are the one forward and the eight backward prediction error fields that are generated simultaneously. Compactly, the input-output relation of the filter is given as a linear combination of input prediction error fields as follows:

$$\mathbf{e}^{(n)} = \mathbf{K}^{(n)} \mathbf{e}^{(n-1)*} \qquad (1)$$

where $\mathbf{K}^{(n)}$ is the 9x9 matrix of reflection coefficients associated with stage (n) given as follows:

$$\mathbf{K}^{(n)} = \begin{bmatrix}
1 & -k_1^{(n)} & -k_2^{(n)} & -k_3^{(n)} & -k_4^{(n)} & -k_5^{(n)} & -k_6^{(n)} & -k_7^{(n)} & -k_8^{(n)} \\
-k_1^{(n)} & 1 & -k_3^{(n)} & -k_2^{(n)} & -k_1^{(n)} & -k_2^{(n)} & -k_7^{(n)} & -k_8^{(n)} & -k_7^{(n)} \\
-k_2^{(n)} & -k_3^{(n)} & 1 & -k_1^{(n)} & -k_2^{(n)} & -k_1^{(n)} & -k_2^{(n)} & -k_3^{(n)} & -k_2^{(n)} \\
-k_3^{(n)} & -k_2^{(n)} & -k_1^{(n)} & 1 & -k_5^{(n)} & -k_4^{(n)} & -k_5^{(n)} & -k_2^{(n)} & -k_3^{(n)} \\
-k_4^{(n)} & -k_1^{(n)} & -k_2^{(n)} & -k_5^{(n)} & 1 & -k_3^{(n)} & -k_8^{(n)} & -k_7^{(n)} & -k_6^{(n)} \\
-k_5^{(n)} & -k_2^{(n)} & -k_1^{(n)} & -k_4^{(n)} & -k_3^{(n)} & 1 & -k_3^{(n)} & -k_2^{(n)} & -k_5^{(n)} \\
-k_6^{(n)} & -k_7^{(n)} & -k_2^{(n)} & -k_5^{(n)} & -k_8^{(n)} & -k_3^{(n)} & 1 & -k_1^{(n)} & -k_4^{(n)} \\
-k_7^{(n)} & -k_8^{(n)} & -k_3^{(n)} & -k_2^{(n)} & -k_7^{(n)} & -k_2^{(n)} & -k_1^{(n)} & 1 & -k_1^{(n)} \\
-k_8^{(n)} & -k_7^{(n)} & -k_2^{(n)} & -k_3^{(n)} & -k_6^{(n)} & -k_5^{(n)} & -k_4^{(n)} & -k_1^{(n)} & 1
\end{bmatrix} \qquad (2)$$

$\mathbf{e}^{(n)}$ and $\mathbf{e}^{(n-1)*}$ are, respectively, the output and the delayed input vectors consisting of forward and backward prediction error fields associated with stage (n) given as follows:

$$\mathbf{e}^{(n)}(i,j) = [e_{00}^{(n)}(i,j)\; e_{10}^{(n)}(i,j)\; e_{11}^{(n)}(i,j)\; e_{01}^{(n)}(i,j)\; e_{20}^{(n)}(i,j)\; e_{21}^{(n)}(i,j)\; e_{22}^{(n)}(i,j)\; e_{12}^{(n)}(i,j)\; e_{02}^{(n)}(i,j)]^T \qquad (3)$$

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* This work is partially supported by Turkish Technology Development Fund with project number TTGV 169.

$$\mathbf{e}^{(n)*}(i,j) = [e_{00}^{(n)}(i,j)\ e_{10}^{(n)}(i-1,j)\ e_{11}^{(n)}(i-1,j-1)\ e_{01}^{(n)}(i,j-1)\ e_{20}^{(n)}(i-2,j)\ e_{21}^{(n)}(i-2,j-1)\ e_{22}^{(n)}(i-2,j-2)\ e_{12}^{(n)}(i-1,j-2)\ e_{02}^{(n)}(i,j-2)]^T \tag{4}$$

The reflection coefficient vector in Eq.(1) is given by:

$$\mathbf{k}^{(n)} = [\,k_1^{(n)}\ k_2^{(n)}\ k_3^{(n)}\ k_4^{(n)}\ k_5^{(n)}\ k_6^{(n)}\ k_7^{(n)}\ k_8^{(n)}\,]^T \tag{5}$$

The first element of these vectors is the forward prediction error field and the remaining eight elements are the backward prediction error fields.

These coefficients can be computed by solving the following normal equations obtained by minimising the mean squared error.

$$\mathbf{R}^{(n-1)}\mathbf{k}^{(n)} = \mathbf{r}^{(n-1)} \tag{6}$$

Here, $\mathbf{k}^{(n)}$ is the 8x1 vector of reflection coefficients hence the name. The elements of the symmetric matrix $\mathbf{R}^{(n)}$ and the vector $\mathbf{r}^{(n)}$ are the cross-correlations between the prediction error fields. The reflection coefficients defined in the fixed structure (6) can also be found adaptively.

3. The Adaptive Algorithm

The adaptive algorithm derived in [9] will be used to update the coefficients of the eight-parameter lattice filters. It briefly states that:

(i) The normal equation at space position (i,j-1) after the minimization of the mean squared error is given as:

$$\mathbf{R}^{(n)}(i,j-1)\mathbf{k}^{(n+1)}(i,j-1) = \mathbf{r}^{(n)}(i,j-1) \tag{7.a}$$

(ii) The adaptive algorithm introduces the correction term for **R**(i,j), namely $\Delta\mathbf{R}(i,j)$

$$\mathbf{R}^{(n)}(i,j) = \mathbf{R}^{(n)}(i,j-1) + \Delta\mathbf{R}^{(n)}(i,j) \tag{7.b}$$

(iii) It also introduces the correction term for **r**(i,j), namely $\Delta\mathbf{r}(i,j)$

$$\mathbf{r}^{(n)}(i,j) = \mathbf{r}^{(n)}(i,j-1) + \Delta\mathbf{r}^{(n)}(i,j) \tag{7.c}$$

(iv) The normal equation at space position (i,j) can also be utilised as:

$$\mathbf{R}^{(n)}(i,j)\mathbf{k}^{(n+1)}(i,j) = \mathbf{r}^{(n)}(i,j) \tag{7.d}$$

The equations (i)-(iv) result in the following adaptive algorithm:

$$\mathbf{k}^{(n+1)}(i,j) = \mathbf{k}^{(n+1)}(i,j-1) - [\mathbf{R}^{(n)}(i,j)]^{-1} [\Delta\mathbf{R}^{(n)}(i,j)\mathbf{k}^{(n+1)}(i,j-1) - \Delta\mathbf{r}^{(n)}(i,j)] \tag{7.e}$$

The matrix inversion lemma is used in order to update the inverse of the matrix $\mathbf{R}^{(n)}(i,j)$ in a recursive fashion:

$$[\mathbf{R}^{(n)}(i,j)]^{-1} = [\mathbf{R}^{(n)}(i,j-1)]^{-1} - \alpha\{[\mathbf{R}^{(n)}(i,j-1)]^{-1} \Delta\mathbf{p}^{(n)}(i,j)[\Delta\mathbf{p}^{(n)}(i,j)]^T[\mathbf{R}^{(n)}(i,j-1)]^{-1}\} \tag{8}$$

with

$$\Delta\mathbf{R}^{(n)}(i,j) = \Delta\mathbf{p}^{(n)}(i,j)\,\Delta\mathbf{p}^{(n)}(i,j)^T \tag{9.a}$$

and

$$\Delta\mathbf{r}^{(n)}(i,j) = e_{00}^{(n)}(i,j)\,\Delta\mathbf{p}^{(n)}(i,j) \tag{9.b}$$

where $\Delta\mathbf{p}^{(n)}(i,j)$ is defined as follows:

$$\Delta\mathbf{p}^{(n)}(i,j) = [e_{10}^{(n)}(i-1,j)\ e_{11}^{(n)}(i-1,j-1)\ e_{01}^{(n)}(i,j-1)\ e_{20}^{(n)}(i-2,j)\ e_{21}^{(n)}(i-2,j-1)\ e_{22}^{(n)}(i-2,j-2)\ e_{12}^{(n)}(i-1,j-2)\ e_{02}^{(n)}(i,j-2)]^T \tag{10}$$

The recursion starts with j=0 with **K**(0,0)=**0** and recursively computes K(i,j) (i=0,1,...,I j=0,1,...,J). The initial condition for $\mathbf{R}^{(0)}$ is the identity matrix **I**.

4. Scope of Quality Control in Raw Textile Fabrics

The general approach in textile quality control is to find the defects on the raw fabrics before any colorful pattern is put on it. Raw fabrics have various types, depending on the material and the color. We have worked on grey level images obtained from white wool and black wool fabrics.

The major defects were, missing threads (causing dark lines on the image), gathered knots and oil stains (causing small dark regions on the image), gathered threads (causing dark curves on the image), and tiny holes on the fabrics. It is clear that there is an inherent texture and there is the defect of a slightly darker tone on the image. Quality control should be able to locate the defect on the image.

5. Defect Detection

Prediction error filtering removes any predictable part of the image and only the unpredictable part of the image remains after filtering. Keeping this in mind, the unpredictable part in an image which is potentially a defect will remain if the image being processed does not have any complex texture which is the case when the textile fabrics is only a raw product.

However when the color of the defects and the fabrics color have close grey levels, which is the case in wool, then using only a prediction error filter will not give as good results as expected. In this case we have to highlight the difference between the background grey level range and the defect grey level range in order to have a large enough prediction error field. When this field is passed through a threshold, a binary image will be achieved where only the defects will remain.

The system we have used to detect and locate defects is given in Figure 1 as a block diagram. We used this system to locate defects in fabric images taken by a black and white camera in a real textile environment. We will now briefly explain the function of each block:

i. Histogram Modification: This operation is done for increasing the range of the dark pixels (comparable to histogram stretching) that are potentially the defects and translating the light pixels towards white. The ultimate goal is an image where the defective pixels are highlighted.

The effects of this modification technique can be observed on Figures 2.a and 2.b. The corresponding histograms are shown on Figures 4.a and 4.b. When the defect and the fabrics color do not have close grey levels, this modification makes the defect more distinct, especially in such defects as oil stains.

ii. Pre-Median Filtering: Histogram Modification causes the background color to be lighter, and increases the range of dark pixels towards black. Therefore isolated pixels appear after this modification. These pixels are not defects so they must be eliminated. We have used the simple 3x3 median filter in all our applications. The effects of this operation can be observed on Figure 3.

iii. Prediction Error Filtering and Thresholding: This operation is performed by using the adaptive 2-D lattice filter. After increasing the difference between the defect and the background, the next step is to find the forward prediction error field of the 2-D lattice filter and thresholding it in order to have a binary image where only the defect will remain and no texture will appear (Please refer to Figure 5).

iii. Prediction Error Filtering and Thresholding: This operation is performed by using the adaptive 2-D lattice filter. After increasing the difference between the defect and the background, the next step is finding the forward prediction error field of the 2-D lattice filter and thresholding it in order to have a binary image where only the defect will remain and no texture will appear (Please refer to Figure 5).

iv. Post-Median Filtering: This operation removes the isolated pixels that may still remain after the thresholding. The effect of this operation can be observed in Figure 6.

6. Conclusion

The main advantage of this approach is that we do NOT need any processing with a non-defective image in order to detect the defects in a defective image. Therefore we actually gain from the number of operations as well. Moreover this scheme can be designed as a very large scale integrated circuit (VLSI). We obtained very successful results in detecting all the defects that we have in our sample set.

The idea of using a 2-D lattice filter structure can also be employed in a different sense. The defective image can be subdivided into blocks and the reflection coefficients can be calculated separately for each block. These coefficients will then be used as a feature set for the identification of each block, whether it is defective or not. However with the probabilistic approach in this paper this is not possible, because the number of data in a block is not adequate for an accurate calculation of the reflection coefficients. Efficient utilisation of data can be achieved by using a deterministic filter instead of a probabilistic one.

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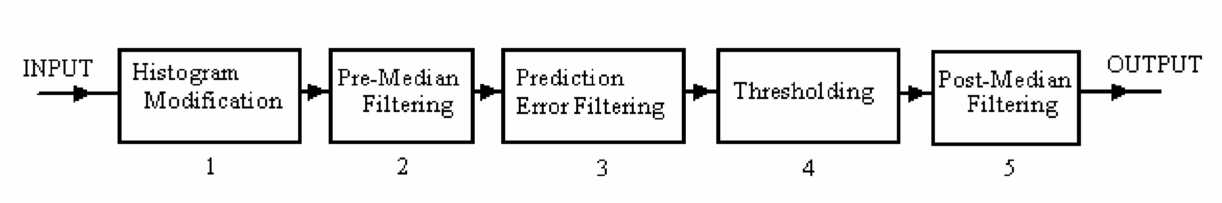

Figure 1 Defect detection scheme as a block diagram

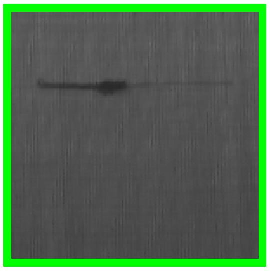

Figure 2.a Original defective white wool image

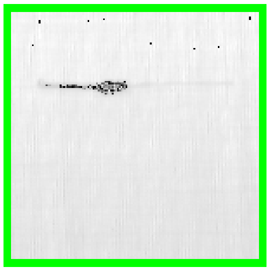

Figure 2.b Image after histogram modification

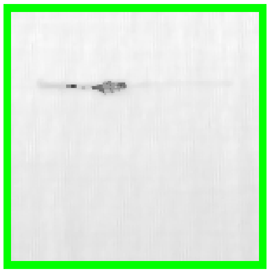

Figure 3 Image after pre-median filtering

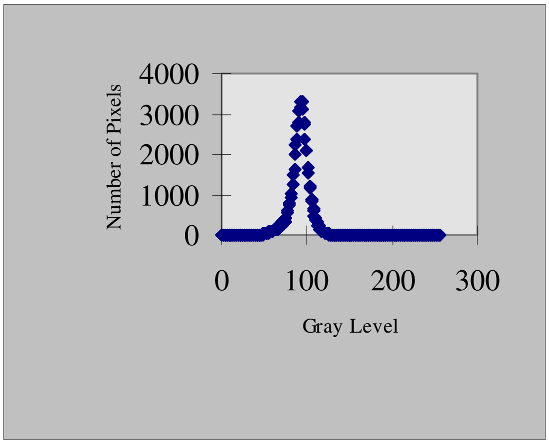

Figure 4.a Histogram of the original image

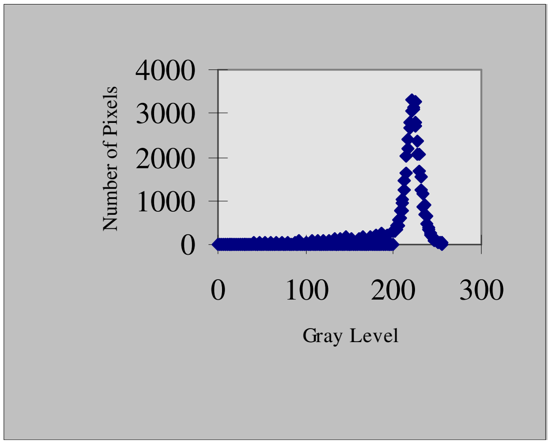

Figure 4.b Histogram of the image after modification

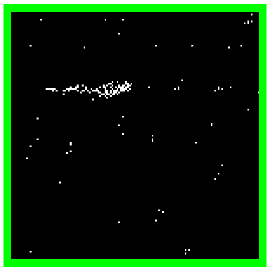

Figure 5 The thresholded forward prediction error field thresholded

Figure 6 Output image after noise removal