CHAPTER 5
Detection of defects in Woven Fabric by Rank Order Operator

5.1 Introduction

The detection of small defects such as knots and broken picks in woven fabric is difficult because of the presence of confused background due to the interlaced periodic structure of the warp and weft, which result a large number of almost regular crossover points. Moreover, hairiness of the fabric introduces high dose of noise into the image pattern of the fabric.

In the Chapter 4, it has been shown that morphological erosion operation can erode the grating structure of the fabric to a certain extent and might be suitable for the identification of defects. However, complete erosion of the background is not possible unless very judicious choice of the structuring element is made. For detection of defects of small size in woven fabric, simple morphological erosion operation with a comparatively large structuring element is not efficient. In such cases, there are always chances of complete erosion of the image. Dilation also may cause the entire cross point background of the image to fill in resulting in a completely dark search space (background). In many cases, there is a need to erode first by a small structuring element and then apply a larger one. This may somewhat solve the problem, however this is not always possible, particularly for the detection of defects in fabric where the failure rate of such a solution is frustratingly high. Therefore, an alternative proposal, such as rank-order filter is investigated.

It is shown in this chapter, that the binary Rank order operation (some times called ordered statistical filtering) [1-2] gives satisfactory result when the expected size of defect is considered in selecting of structuring element. Moreover, the rank order operator has unique property of image smoothing and presenting edges at the same time and it is very efficient for noise removal. In a woven fabric, repetition of the interlaced grating structure is not very accurate and therefore rank order operation proves to be an efficient tool for defect detection.

In recent years, several rank-order structuring filters are proposed [3]. These filters are roughly divided into two categories. The set of adaptive rank-order filters fall [4-8] under the first category, while the second class encompasses structure preserving rank-order filters [9-11]. Adaptive rank-order filters are used on images with low signal-to-noise ratios and some a priory knowledge or local statistics are required for processing. The main advantage of the non-adaptive type lies in the fact that the extensive use of local statistics is not necessary.

The rank order filter while applied on binary image is also called an order statistic filter [2], a Ξ filter [12], r-out-of-n filter [13], or voting logic [14]. A binary rank order operations can be replaced by operations of counting the number of image points that contacts the points of the structuring element probe and marks the reference point in the output image if at least a given percentage of points contact the probe. The percent point or the threshold is a variable and is adjusted for good performance in a particular application.

5.2 Binary convolution operation

The rank order operation can be performed by a linear convolution between input image and reference image followed by thresholding of the convolution output [15]. Simplest image convolution operation of image is a process that copies one image at each pixel location of another while allowing for the effects of all pixel values in the area where the copy takes place. A multiplying, adding and shifting operation accomplish this. A convolution, *c(p)* of a binary image *A(u)* by kernel or structuring element *B(u)* is given by

$$c(p) = \sum_{u} A(p-u)B(u) = A * B \tag{5.1}$$

where, p and u are two-dimensional spatial vectors, $u, p \in Z^2$, and the summation is over the Z domain of the image.

5.3 Binary Nonlinear Rank Order Filter

Widely employed nonlinear and locally adoptive filters are rank order filters. The threshold operation X_t is applied to equation-5.1, at threshold t, to get the output result after rank order filter operation.

$$R_t(A,B)(p) = X_t\left(\sum A(p-u)B(u)\right) = X_t(A * B) \tag{5.2}$$

For a rank order operator R_t expressed in this from, threshold t is the rank. The threshold operation X_t is defined as

$$\begin{aligned} X_t &= 1 \quad \textit{if} \quad c(p) \geq t \\ &= 0 \quad \textit{otherwise} \end{aligned} \tag{5.3}$$

It may be noted that the rank-order operator is a generalization of the morphological erosion and dilation operations. Erosions and dilations are convolutions with maximum and minimum threshold value respectively.

For segmenting a gray-level image into a binary image threshold segmentation is used [16]. $I(i,j)$ is the gray level pixel value of point (i,j) of the input fabric image and $X(i,j)$ is the gray level of point (i,j) of the out put fabric image. If 1 represent white pixel, 0 represent black pixel and T is the threshold value then the binary image from gray level image is obtained by applying the following rule.

$$\begin{aligned} X(i,j) &= 1, \; if \quad I(i,j) \geq t \\ &= 0, \quad otherwise \end{aligned} \tag{5.4}$$

It is assumed that the threshold value is independent of the spatial coordinates (i,j) and also threshold value is independent of local properties of the point.

5.4 Choice of the proper rank of the Rank order operator

Two problems are encountered while applying the rank order operator for defect detection in fabric. They are related to the (a) choice of reference image (i.e. structuring element) and (b) the choice of the rank. Rank order operator rotates in planar geometric structure, which is altered by probing with a structuring element called reference image. Each operation uses the reference image to determine the geometrical filtering process. The reference image or the structuring element of the operator is therefore a function defined in the domain of the spatial pattern of the operator. The value of each pixel of the domain is the weight or coefficient employed by the pixel position. The selection of the size and shape of the reference image is hence an important step for defect detection. When the size of the reference image is almost same to the size of the defect to be detected the most efficient and optimum detection capability is expected. Evidently the size of the reference image can be ascertained from priory knowledge of the likely defect in woven fabric.

The rank selection is based on the boundary characteristics. One of the most important aspects in selecting a rank is the capability of reliably identifying the mode peaks in a given image histogram. This is particularly important for automatic threshold selection in situations where image characteristics can change over a broad range of intensity distributions as in the case of woven fabric. Therefore the rank of the operator has to be decided also from a priori knowledge of the periodicity of the fabric structure and the width of the warp and weft yarns.

The rank of a particular operation is a function of the reference image or the structuring element B and the intensity values of the test fabric A. A simple relation is established between the rank R and the dimension D of the structuring element B and the maximum value Z of the convoluted matrices for quick selection of a rank for a particular operation. The relation is given by

$$R = 255(k)(D) - Z \tag{5.5}$$

where, k is a positive low value and

$$Z = \max(A \otimes B) \tag{5.6}$$

where $A \otimes B$ is the dilation of A with the structuring element B.

5.5 Laser based optoelectronic system for rank order filtering operation

The optoelectronic arrangement for performing rank-order filtering is shown in figure 5.1. A collimated laser beam illuminates the test fabric and is imaged by a pair of Fourier transform lens placed at focal lengths. A CCD camera, connected to a computer via a frame grabber card, captures the image. The gray test image, captured by the CCD camera is binaries using a proper threshold value. The binary image is then convolved with a suitable structuring element. The selection of the size of the structuring element is guided by *priory* knowledge of the size of the defects. If the defect in the test fabric mismatches with the selected structuring element or the reference image then the later is replaced from the created library of the reference image.

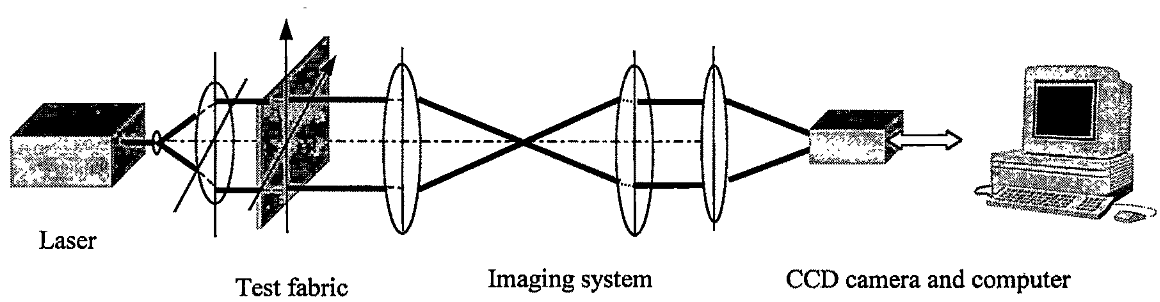

Figure 5.1 : Optoelectronics system for defect detection by Rank order filtering method

To get better result the threshold value (i.e. the rank) is selected using equation 5.5. If A (the test fabric) is a $(m \times n)$ matrix and if B (the structuring element or the reference image) is a $(m_1 \times n_1)$ matrix, then the convoluted matrices has dimension $(m \times n) \times (m_1 \times n_1)$. So the dimension of the output matrix increases correspondingly. The conversion of $(m \times n) \times (m_1 \times n_1)$ matrix to $(m \times n)$ output matrix eliminates the data outside the region of interest.

5.6 Experimental results and discussions

Figure 5.2a shows the presence of a knot as defect in the test fabric and figure 5.2b is the thresholded image of figure 5.2a. A structuring element of size 15 X 15 is used for rank order filtering of the basic grating structure of the fabric at the value of k = 0.657. It is seen that the knot is extracted efficiently in the figure 5.2c and the detection is much better than that done by the method of erosions (figure 4.5a or figure 4.19a of chapter 4). In contrast to the erosion operation of spatially filtered image, the size of the knot is not reduced and is maintained in the detection process of the rank order filtering. For the detection of a small knot, the effect of selection of structuring element assumes importance. Figure 5.3a and figure 5.3b shows the presence of a small knot and its thresholded image respectively. The rank order filtered image shown in figure 5.3c, with a structuring element of size 13 X 16 at k=1 almost obliterates the existence of the knot. However, all noise and the grating structure is completely removed. Detection of knot by rank order filtering in coarse fabric of figure 5.4a is shown in figure 5.4c. The processing is done with a structuring element 25 X 25 at k = 9.2.

A scrutiny of figure 5.5a will show the existence of not only a thick weft at the bottom but also the existence of a slightly thicker yarn (weft) on the upper portion of the fabric. The existence of the defect of slightly thicker yarn escapes visual inspection and the can not be detected by morphological operations even. However, by selecting an elongated structuring element 4 X 132 at k = 0.657, matching closely the diameter of the yarn, the process of rank order filtering is able to detect even this yarn as defect (figure 5.5c). The detection of thicker yarn of figure 5.6a is also possible as indicated in figure 5.6c. Figure 5.6b shows the thresholded image of figure 5.6a.

However, when rank order filtering is applied on the thresholded image (figure 5.6b) for the detection of a thick yarn shown in figure 5.6a with a structuring element 132 X 4, the detection is not very smart at k = 0.833. This is because of the reason that dimensions of the grating structure matches with the diameter of the defective yarn. Therefore the detection at the corners of the figures is not very efficient. .

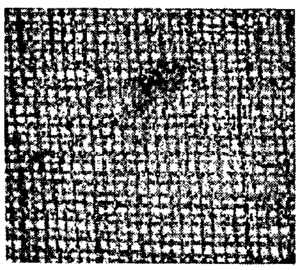

Figure 5.2a
Image of fabric with a knot as defect

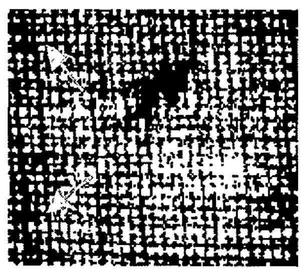

Figure 5.2b
Thresholded image of figure 5.2a

Figure 5.2c
Detection of knot

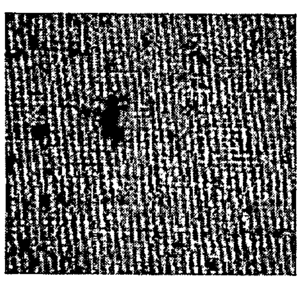

Figure 5.3a
Image of fabric with a knot as defect

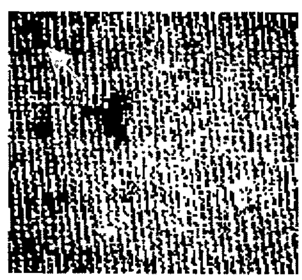

Figure 5.8a
Thresholded image of figure 5.3a

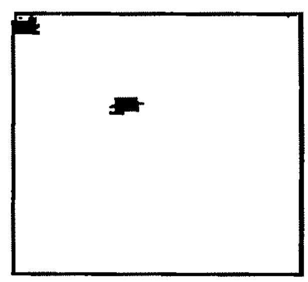

Figure 6.2b
Detection of knot

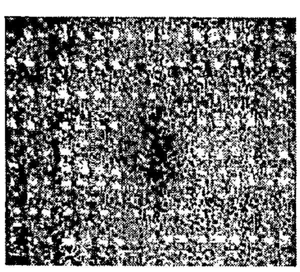

Figure 5.4a
A knot in a coarse fabric

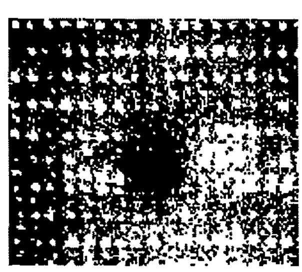

Figure 5.4b
Thresholded image of figure 5.4a

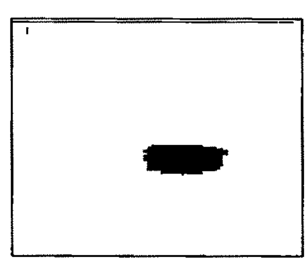

Figure 5.4c
Detection of knot

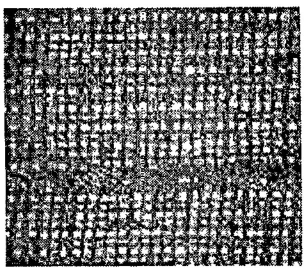

Figure 5.5a
Defective Fabric with a thick weft

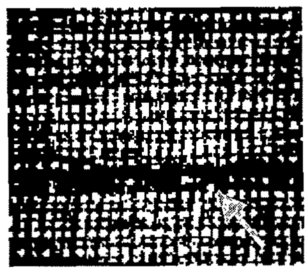

Figure 5.4b
Thresholded image of figure 5.5a

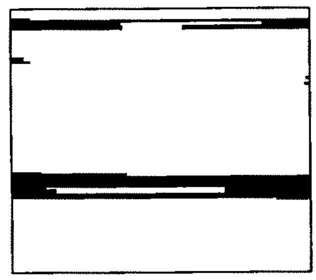

Figure 5.5c
Detection of a thick weft

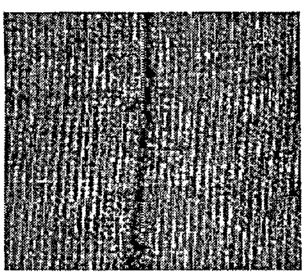

Figure 5.6a
Fine fabric with a thick warp as defect

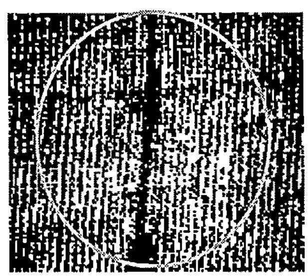

Figure 5.6b
Thresholded image of figure 5.6a

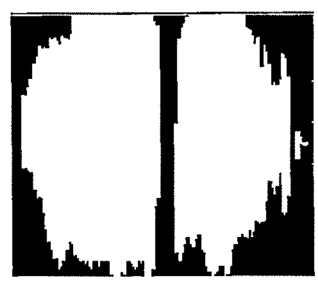

Figure 5.6c
Detection of a thick warp

5.7 Conclusion

It has been shown in Chapter 4 that morphological erosion operation on fabric image helps in detecting defects to some extent. The detection capability improves if the image is spatially filtered to remove the grating structure of the fabric. Since the spatial filtering introduces speckle and other noise, the efficacy of the technique is lost to a great extent.

In this chapter it is shown that detection capability is greatly improved by rank-order filtering. The method offers two flexible controls. The structural element can be selected according to *a priori* knowledge of the defect. Secondly, the rank can be selected to suit a particular noisy situation. It has been established that very good detection is possible for a knot in all types of fabric by rank order filtering technique. It is also shown that proper selection of the structuring element enhances the chance of detection of defects which otherwise may not be very distinct even during visual inspection.

References

[1] H. Heygester, "Rank filters in digital image processing": Proc. 5th Int. Conf. on pattern Recognition, Florida, p1165, 1980

[2] A. H. David, *Order Statistics*, Wiley NY, 1970

[3] G. R. Arce and R. E. Foster, "Detail preserving ranked order based filters for image processing"; IEEE, Trans, Acou. Speech & Sig. Processing, Vol. 37, No 1, p83, 1989

[4] Y. H. Lee and A. T. Fam, "An edge gradient enhancing adaptive order statistic filter"; IEEE, Trans, Acou. Speech & Sig. Processing, Vol. 35, No 5, p83, 1987

[5] L. S. Davis and A. Rosenfield, "Noise cleaning by iterative local averaging", IEEE Trans. Syst. Man Cyber, Vol. 8. No 9, 1978

[6] I. Song and S.A. Kassam, "A class of rank filters based on Wilcoxon signed rank statistics" Proc. 24th Annual Allerton Conf.. Monticello, IL, Oct. 1986

[7] Y. H. Lee and S.A. Kassam, "Generalized Median filtering and related non-linear filtering techniques", IEEE, Trans, Acou. Speech & Sig. Processing, Vol. 33, No 5, 1985

[8] A. Kundu, S. K. Mitra and P. P. Vaidyanathan, "Application of two-dimensional generalized mean filtering for removal of impulsive noises from images", IEEE, Trans, Acou. Speech & Sig. Processing, Vol. 32, No 6, 1984

[9] A. Nieminen, P. Heinonen and Y. Neuvo, " A new class of detail-preserving filters for image processing", IEEE Trans Pattern Anal. Machine Intelli., Vol 9, No. 1, 1987

[10] G. R. Arce and M. P. McLoughlin, "Theoretical analysis of max/ Median filters", IEEE, Trans, Acou. Speech & Sig. Processing, Vol. 35, No 1, 1987

[11] R. L Stevenson and G. R. Arce, "Morphological filters: Statistics and further syntactical properties. IEEE Trans. Circuits & system, Vol 34. No 11, 1987

[12] K. Preston, "Ξ Filters", IEEE, Trans, Acou. Speech & Sig. Processing, Vol. 31, No 4, 1983

[13] B. I. Justusson , "Median filtering: Statistical properties", *Two dimensional signal processing, Springer-Verlag, Germany,* 1981

[14] E. R. Dougerty, *"Mathematical morphology in image processing" Mercel Dekker, NY,* 1993

[15] A. F. Gerritsin and P. W. Verbeek, "Implementation of cellular logic operator using 3 x 3 convolution and table lookup hardware" Comp. Vision, Graphics and Image Processing, Vol 27 no1, 1984

[16] S. R. Sternberg, "Grayscale morphology" Comp. Vision, Graphics and Image Processing, Vol. 29 no3, 1986