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# Real-Time Denim Fabric Inspection Using Image Analysis

**Abstract**
*In spite of using modern weaving technology, many types of fabric defects occur during production. Most defects arising in the production process of a fabric are still detected by human inspection. A machine vision system that can be adapted to different types of fabric inspection machines is proposed in this study. Image frames of denim fabric were acquired using a CCD line-scan camera. An algorithm was developed by using the Gabor filter and double thresholding methods. The performance of the algorithm was tested real-time by analysing a denim fabric sample which contained six types of defects: hole, warp lacking, weft lacking, soiled yarn, water soil and yarn flow (knot). The defective regions of the denim fabric sample were detected and labelled successfully.*

**Key words:** *Image processing, real-time fabric inspection, Gabor filter, denim fabric, machine vision system.*

## Introduction

The deformed regions which damage the appearance and performance of a fabric may be called 'a fabric defect'. In modern weaving technology, many types of fabric defects still occur, The sources of which are many, such as the yarn quality used in weaving, its preparation operations or weaving mechanics. The defects encountered within production must be detected and corrected at the early stages of the production process. Most defects arising in the production process of a fabric are still detected by human inspection. A woven fabric beam is placed on the fabric inspection machine and wound from the back to the front beam while passing over an illuminated surface. The quality control personnel has to scan nearly 2 meters width of fabric (***Figure 1***) and must detect small details that can be located in a wide area that is moving through their visual field. The detection and classification of these defects are time consuming and tiring procedures. In the best case, a quality control person can detect no more than 60-70% of the present defects, and cannot deal with a fabric wider than 2 meters. It is observed that the inspection speed of a fabric woven with an efficiency of even 97% is 30 m/min, and only about 60% of the defects are detected [1].

The problem is to design a machine vision system for fabric inspection machines and develop an algorithm for fabric defect detection automatically. The system will be simple, portable and easily adaptable to all types of fabric inspection machines. Fabric manufacturers can adapt this system by using their existing fabric inspection machine. The automated defect detection system will enhance product quality and result in improved productivity to meet both customer demands and reduce costs associated with off-quality. The employment cost will be reduced by replacing human vision detection with automatic visual detection, where fabric defects will be evaluated objectively. A database of the defects can be formed and they can then be analysed realistically. Consequently statistical evaluation of denim quality can be achieved. The feedback data obtained from the automatic inspection system may provide the production of high quality fabrics with fewer defects in a shorter time.

## Survey on image processing techniques

Many attempts are made to replace traditional human inspection by automated visual systems using camera nodes and

***Figure 1.*** *Traditional fabric inspection.*

*Table 1. Fabric sample specifications.*

| | |
|---|---|
| Pattern | 3/1 (s) twill |
| Warp yarn number | Ne 16/1 Open-end |
| Weft yarn number | Ne 10/1 Open-end |
| Warp sett, ends/cm | 45 |
| Weft sett, picks/cm | 20 |
| Warp crimp, % | 12 |
| Weft crimp, % | 1.5 |
| Weight per square meter (with sizing), g/m$^2$ | 323 |
| Cover factor | 33.8 |
| Reed number, dents/10 cm | 110 |

image processing routines. Different types of image processing methods such as Gabor filters, Wavelet analysis, and the Fourier Transform have been applied for fabric defect detection. Artificial Intelligence (AI) methods such as the Neural Network (NN), Fuzzy Logic (FL) and Genetic Algorithm (GA) are also used for defect detection and classification studies. Studies are generally performed off-line using digital images [2]. Sample images are obtained by using different types of image acquisition devices or from a defective fabric image database. There are fewer studies on real-time defect detection than off-line ones.

Celik et al. proposed two different defect detection algorithms based on the wavelet transform [3] and linear filters [4] using the same system presented in this study.

Karayiannis et al. [5] presented a pilot system for fabric defect detection and classification in real-time. Double thresholding, binary filtering, binary labelling, multi-resolution decomposition via the wavelet transform, and statistical texture feature extraction methods were used for image analysis and defect segmentation. Eight types of classification were performed: no error, black vertical error, white vertical error, wrinkle, black horizontal error, white horizontal error, black spot, and white spot. This system is able to classify the eight defect types with a maximum accuracy of 94%.

Goswami and Datta [6] used morphological operations such as erosion and opening operations as well as the Fourier Transform for fabric image analysis. Fabric images that contain a knot and thick yarn were detected by morphological erosion operations.

Mak et all [7] proposed a prototype of a real-time computer vision system for detecting defects in textile fabrics. The Gabor function was used for defect segmentation. Both on-line and off-line tests were performed using the prototype system.

Han and Zhang [8] derived one even symmetric Gabor filter mask and one odd symmetric Gabor filter mask from an optimal Gabor filter. The parameters of the optimal Gabor filter were obtained by Genetic Algorithm (GA). It was concluded that even the symmetric Gabor filter was good at detecting blob-shaped fabric defects like knot, and the odd symmetric Gabor filter was adept at detecting edge-shaped fabric defects like miss pick. The performance of the system is expressed as 95.24% over all the detection rate.

Cho et al. [9] proposed a prototype system for fabric defect detection. The defects inspected by the system were warp float, broken pick, hole and oil spot. It was stated that a nearly perfect recognition rate was obtained for an oily spot and spot. However, the recognition rate of the warp and pick float was about 80%.

Conci & Proença [10] compared the results of three image-processing approaches such as fractal dimension, thresholding, and edge detection. In this study, the relationship between the efficiency of each approach and the type of fabric fault were presented. Ten types of faults were considered, all of which were plain weave. Tests were carried out using 100 images of fabrics. The results showed that fractal dimension was the most reliable method as it correctly detected all the types of defects. By using edge detection, 98% of these faults were correctly detected, while the threshold approach correctly identified 82% of these defects.

Hu and Tsai [11] studied the best packet wavelet transform to detect and identify fabric defects. The three main effects on the classification rate of fabric defect inspection comprising wavelets with various maximum vanishing moments, different numbers of resolution levels, and differently scaled fabric images were investigated. Four kinds of fabric defects such as missing ends, missing picks, broken fabrics, and oil stains were used. A back propagation neural network (BPNN) was used to classify the fabric defects. It is stated that the total classification rate reached 100% in the case of a wavelet function with a maximum vanishing moment of 4 and three resolution levels. It is claimed that increasing the resolution level is advisable than the maximum vanishing moment.

Mak, Peng & Yiu [12] detected fabric defects by using the Gabor wavelet network and morphological operations, in which plain and twill fabric samples were used. The designed algorithm was tested off-line and real-time on a designed prototype system. It is stated that off-line tests were performed with a 97.4% overall detection (OD) rate. The real-time detection process was conducted with a false alarm rate of 3.3%.

Furferi & Governi [13] submitted a system for the detection and classification of commonly occurring circular knitted fabric defects using a Radon transform and Artificial Neural Network (ANN). It is denoted that the system detects only spots and horizontal and vertical defects. The system performance is stated as 90% for defect detection and 88% for classification.

## Materials

Since undyed and indigo dyed denim fabrics are the most commonly produced textile products in the cities of Gaziantep and Kahramanmaraş in Turkey, the material used for defect detection was selected as undyed denim fabric. The material was supplied by Prestij Dokuma Ltd. Şti. in Gaziantep. Specifications of the fabric sample are given in ***Table 1***.

## Image processing method

An algorithm [14] for denim defect detection was built using the Gabor function, noise removing filters, the double thresholding binarization method, as well as dilation and erosion operations (***Figure 2***). The algorithm developed was firstly applied off-line [15]. After a high true detection ratio (96.7%) was obtained, it was then performed real-time in this study. Fabric defect segmentation is achieved by using the Gabor function. The defect segmentation process is achieved by attenuating the background information and accentuating the defective regions. Different Gabor function types are proposed in literature [16 - 18]. The objectives of using the Gabor function in image analysis are; to identify different textured and non-textured regions, to segment different texture regions and to extract boundaries between texture regions. The Gabor function consists of real and imaginary parts. Kumar and Pang claimed that the contribution from the imaginary Gabor function was very small when Gabor functions were used in defect detection [19]. The real part of the Gabor function (***Equation 1***) is used for this application [20];

$$g_{\lambda,\theta,\sigma,\gamma,\varphi}(x,y) = = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right)\cos\left(2\pi\frac{x'}{\lambda} + \varphi\right) \quad (1)$$

where,

$$x' = x\cos(\theta) + y\sin(\theta)$$
and (2)
$$y' = y\cos(\theta) - x\sin(\theta)$$

$\lambda$ is the wavelength of the cosine factor of the Gabor filter in pixels. $\theta$ specifies the orientation of the normal to the parallel stripes of a Gabor function in degrees. $\varphi$ is the phase offset specified in degrees. is the aspect ratio, specifying the ellipticity of the support of the Gabor function. $\sigma$ denotes the standard deviation of the Gabor function. All these parameters are determined experimentally by using a defect-free fabric sample as a template during the study.

Firstly fabric identification processes must be achieved, therefore thresholding limits must be determined, as presented in the flowchart of the algorithm (***Figure 2***). The limits are determined by using a defect-free fabric sample as a template. The maximum and minimum limits are calculated by using average and standard deviation values of the template fabric image frame as in ***Equation 3*** [9].

$$T_{1,2} = = mean[a(i,j)] \pm w \times mean[std(a(i,j))] \quad (3)$$

$T_1$ is the upper limit and $T_2$ is the lower limit of the binarization process, and 'w' is the weighting factor, determined experimentally between 2 and 4.

As the fabric is wound, the camera captures image frames, which may have noises because of the nonuniform brightness distribution, small cotton impurities and non uniform fabric motion. The noises are removed by using a Wiener low-pass filter and mean value filters. Then the image is convolved with the Gabor filter, whose optimum parameters are predetermined experimentally. The Gaussian filter given in ***Equation 4*** [21] is used for image smoothing after Gabor filter convolution.

$$h_{g(n_1,n_2)} = e^{\frac{-(n_1^2 + n_2^2)}{2\sigma^2}} \quad (4)$$

where, $n_1$ and $n_2$ are the locations of the related pixel, and $\sigma$ is the variance of the neighborhood. The sizes of the Gaussian filter, Wiener filter and mean value filter are set to 3 × 3. The binarization process is given as follows [9];

$$B(i,j) = = \begin{cases} 0, & T_{min} \le a(i,j) \le T_{max} \\ 1, & a(i,j) < T_{min} \text{ or } a(i,j) > T_{max} \end{cases} \quad (5)$$

where, $B(i,j)$ is binary image and $a(i,j)$ the Gaussian filtered image. If the grey level value of a pixel value is between $T_1$ and $T_2$, it is allocated as 0. Otherwise it is set as 1. The value of 0 means no defect and 1 that the cell has a defect or noise in the binary image.

Some noise components may exist after the binarizsation process. These are removed by using dilation and erosion operations, indicated as $A \oplus B$ and $A \ominus B$, respectively; these are morphological operations. Structuring element $B$ slides over image $A$ from the top to the left bottom right by applying convolution with the same area of the image. The dilation operation means that the center pixel of the structuring element is placed on each background pixel. If any of the neighborhood pixels are foreground pixels value 1, then the background pixel is changed to the foreground. In the erosion operation, the centre pixel of the structuring element is placed on each foreground pixel value 1. If any of the neighborhood pixels are background pixels value 0, then the foreground pixel is switched to the background [22, 23]. The process sequence continues until the camera runs and captures the image.

## Automatic fabric inspection system

The inspection system consists of an industrial fabric inspection machine, illumination unit, CCD line-scan camera, frame grabber, rotary encoder and host computer (***Figure 3***). It is available at Gaziantep University, Textile Engineering Department, Turkey. Fabric inspection machine adjustments are carried out using its control panel. Camera settings and image analysis processes are performed using a computer. The fabric inspection machine is a Concorde CDK2 Model, made by the Cihansan Company (Turkey). The fabric winding speed can be adjusted between 0 - 50 m/min. The fabric winding speed and tension of the fabric can be controlled by means of a control panel.

The illumination is an essential parameter affecting the input data of the visual inspection system. The light intensity has a significant effect on the quality of images captured and the performance of the defect detection algorithm. A high intensity and uniform light illumination source is required along the fabric width

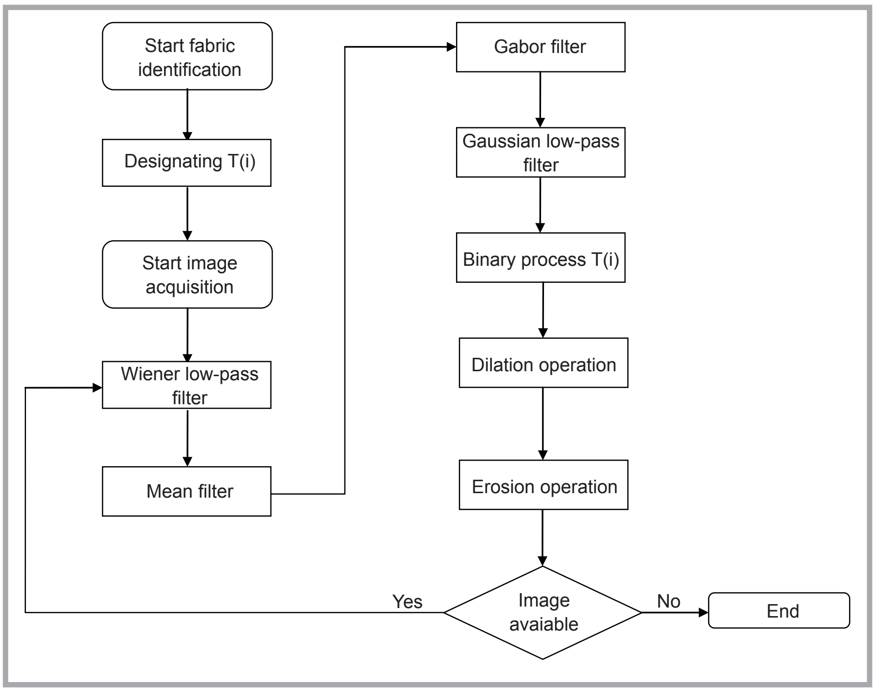


***Figure 2.*** *Flowchart of fabric inspection algorithm.*

*Table 2. Technical properties of line-scan camera.*

| | |
|---|---|
| Line resolution of the camera, pixels | 2048 |
| Maximum line rate, kHz | 18.7 |
| Pixel clock speed, MHz | 40 |

for a higher true detection performance. Different illumination sources can be used such as incandescent, fluorescent, mercury-vapour, sodium-vapour and LEDs (Light Emitting Diodes). The fabric inspection machine has two illumination units, one of which is above the fabric surface and the other one below. Both of the lightening units have eight fluorescent lamps. Because of the weak light intensity, being far away from the fabric surface, and inflexible structure, an additional lightening unit is needed to be designed. The additional illumination unit with LED strips is installed properly on the fabric inspection machine without changing the existing illumination unit frame. Since only front lighting is sufficient for defect detection, back lightening is not necessitated.

A Basler L103k-2k line-scan camera is used for image frame capturing. Technical properties of the camera are given in ***Table 2***. The fabric sample is scanned in the warp direction. The camera is connected to the frame grabber (National Instruments PCIe 1427) via a camera link. As the line-scan camera captures the image frames line by line, the frame grabber transmits the digital image data to the computer. Synchronisation between the fabric winding and image capturing is conducted using a 4096 ppr (pulse per revolution) rotary encoder.

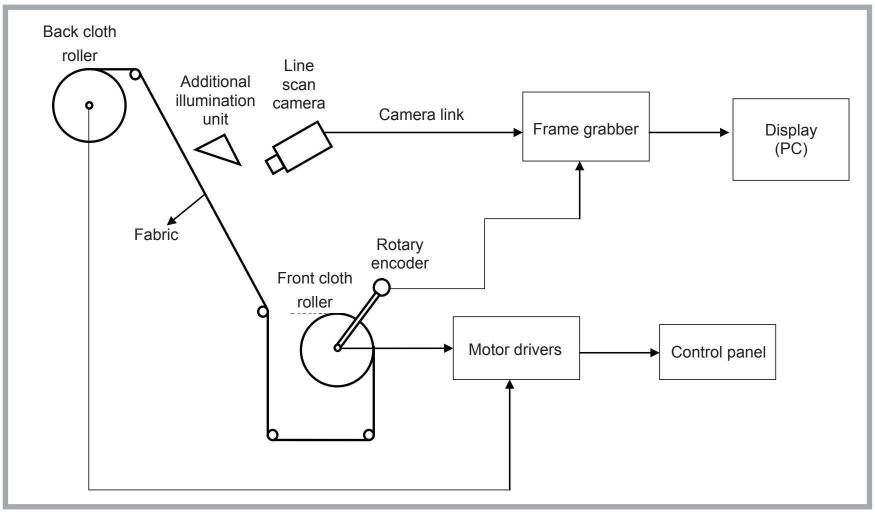


***Figure 3.*** *Fabric inspection system configuration.*

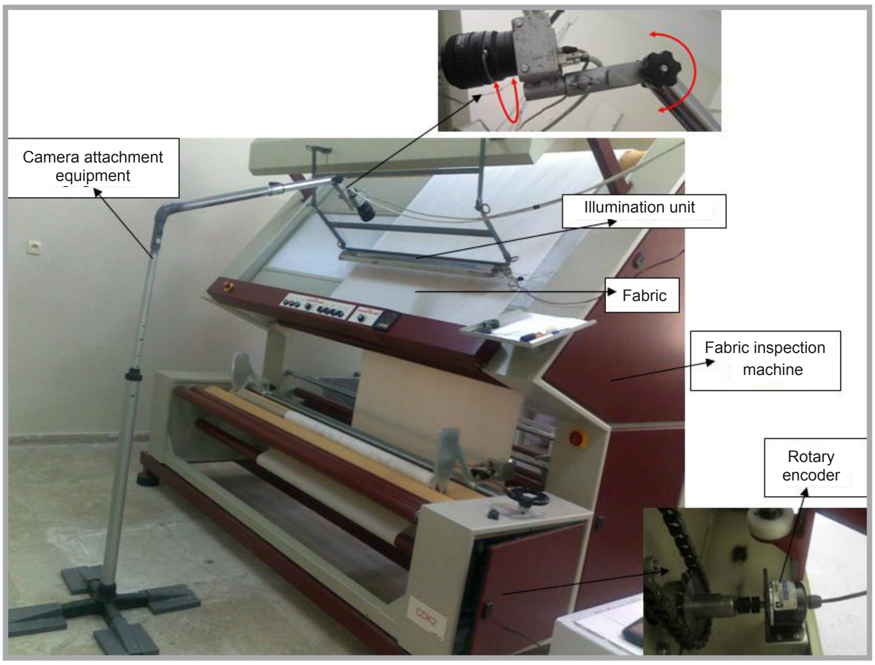


***Figure 4.*** *Real-time fabric inspection system.*

## Real-time experimental results

The sample has defect-free regions and six types of defects: hole, warp lacking, weft lacking, soiled yarn, water soil and yarn flow (knot). Since it is difficult to encounter all these on the same fabric piece, some of them are made manually by distributing randomly. The exposure time of the camera is adjusted according to the light intensity of illumination source and the resolution of the camera. The exposure time restricts the fabric winding speed. When the fabric winding speed is over the exposure time adjusted, the image quality gets lower and a deformed image is obtained. Hence the defective areas of the image frame cannot be detected, decreasing the performance of the system. Because of the illumination source limitations, the maximum fabric winding speed achieved is 9.5 m/min. The resolution of the camera is 0.12 mm per pixel in both the horizontal and vertical directions. The view range of the camera is 246 mm (2048 pixel × 0.12 mm/pixel). The image frame size is arranged as 300 lines × 2048 pixels.

The automatic inspection system is given in ***Figure 4***. Camera attachment equipment is designed to place and carry the camera. This equipment is used to adjust the position angle of the camera and the distance between the camera and fabric surface. The view range of the camera and corresponding resolution in the weft direction can be adjusted by changing the distance between the camera and fabric surface. Due to the portable and easily adjustable design of the equipment, it can be adapted and used with different types of fabric inspection machines.

An additional illumination unit is designed to place the LEDs. The additional unit is placed on the frame of the upper lightening unit. This unit consists of five links, with two on both sides of one illumination frame. The frame where the LED strips are placed is of 1 meter length. The position of the unit can be adjusted by using three joints on both sides of the lightening frame. The links are joined to each other with bolts and nuts. The distance between the illumination unit and fabric surface and the angle of the illumination frame can be adjusted to any position required. When the proper position is determined, the links of the unit are fixed by squeezing the joint bolts.

***Figure 5*** presents real-time experimental results applied to six different defects. The defective area of the fabric images are segmented successfully. The performance of the system is evaluated statistically (***Table 3***) for 618 sample fabric images including different types of defects. The statistical criteria are determined as True Detection (TD), False Detection (FD), Misdetection (MD) and Overall Detection (OD) [8].

The system can detect defective areas of a denim sample with an average TD rate of 91.7% and FD rate of 6.5%. Among the five defect types, the highest TD ratio is obtained with the hole defect and the lowest with the yarn flow defect. The system is adequately successful with an OD ratio of 99.6%.

Because of the camera resolution and light intensity of the illumination unit, warp lacking and weft lacking type defects with a width smaller than 2 mm cannot be detected exactly. Soiled yarn and hole type defects even as small as 1 mm width can be inspected successfully.

## Conclusions

Although many different vision system alternatives are proposed for real-time defect detection [1, 5, 7, 24], a new fabric inspection machine design is presented [14]. A portable vision inspection system that is easily adaptable to any fabric inspection machine was developed in this study. Thus denim manufacturers can easily afford this system and set it up on their existing fabric inspection machines. By using this system the fabric inspection process can be conducted in a shorter time and fewer fabric quality inspection personnel may be needed. Fabric inspection processes can be achieved quickly with the elimination of any disputes over the quality of the fabric.

The performance of the system is tested only on denim fabric. Other types of fabrics have not been experimented on yet; this will be achieved in further studies on the same prototype system. The system is tested only for six defect types: warp lacking, weft lacking, hole, soiled yarn, water soil and yarn flow. All the defective areas are detected successfully with

***Table 3.*** *Evaluation of system performance.*

| | Defect-free | Warp lacking | Weft lacking | Hole | Soiled yarn | Yarn flow | Water stain |
|---|---|---|---|---|---|---|---|
| ***Number of frames*** | 227 | 104 | 57 | 86 | 78 | 55 | 11 |
| ***TD*** | 219 | 88 | 50 | 86 | 77 | 46 | 10 |
| ***FD*** | 8 | 16 | 6 | 0 | 0 | 9 | 0 |
| ***MD*** | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| ***OD*** | 227 | 104 | 56 | 86 | 77 | 55 | 10 |
| ***TD rate, %*** | 96.5 | 84.6 | 87.7 | 100.0 | 98.7 | 83.6 | 90.9 |
| ***FD rate, %*** | 3.5 | 15.4 | 10.5 | 0.0 | 0.0 | 16.4 | 0.0 |
| ***MD rate, %*** | 0.0 | 0.0 | 1.8 | 0.0 | 1.3 | 0.0 | 9.1 |
| ***OD rate, %*** | 100.0 | 100.0 | 98.2 | 100.0 | 98.7 | 100.0 | 100.0 |

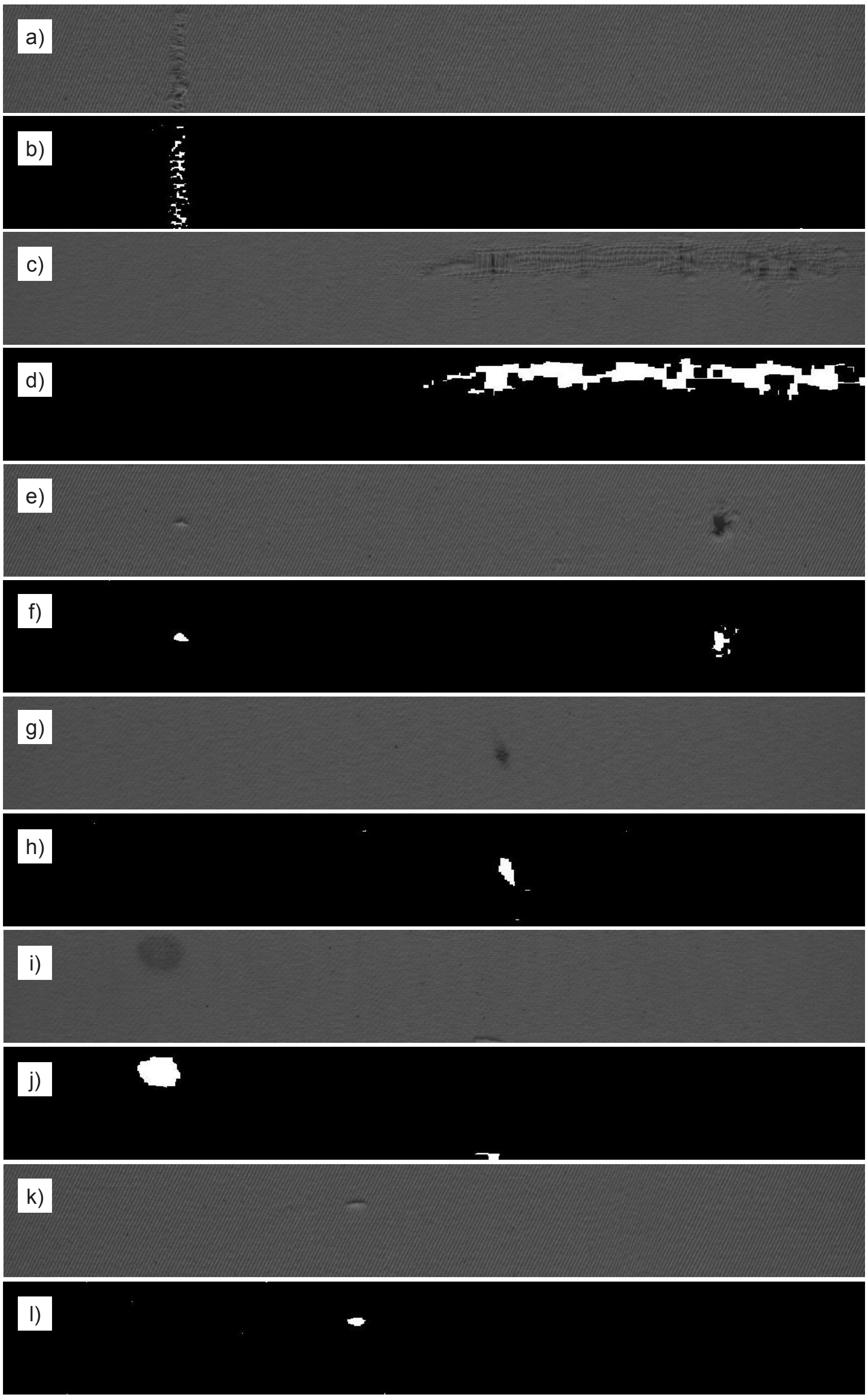


***Figure 5.*** *Defects and image processing results: a) warp lacking, b) binary image of warp lacking, c) weft lacking, d) binary image of weft lacking, e) hole, f) binary image of hole, g) soiled yarn, h) binary image of soiled yarn, i) water soil, j) binary image of water soil, k) yarn flow, l) binary image of yarn flow.*

an overall detection rate of 99.6%. In other studies the Gabor filter is used for fabric defect detection with an overall detection rate of 95.24% [8] and 98.7% [24], whereas a higher true detection rate is obtained in this study. Studies of the defect detection algorithm and system are on-going . Different kinds of denim defects will be experienced, hence the inspection range of the system will be increased. The defect detection rate will be increased by using more sophisticated computers. Also the size of the defects detected is going to be decreased by using higher resolution cameras and a specially manufactured more intensive illumination unit.

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## References

1. Anagnostopoulos C, Vergados D, Kayafas E, Loumos V, Stassinopoulos G. A computer vision approach for textile quality control. *J. of Vis. and Comp. Ani.* 2001*;* 12: 31–44.
2. Bodnarova A, Bennamoun M, Latham S. Optimal Gabor filters for textile flaw detection. *Pattern Recognit.*2002; 35: 2973 – 2991.
3. Çelik Hİ, Dülger LC, Topalbekiroğlu M. Development of a machine vision system: real-time fabric defect detection and classification with neural networks, *J. Text. Inst.* 2014; 105, 6: 575-585.
4. Çelik Hİ, Dülger LC, Topalbekiroğlu M. Fabric defect detection using linear filtering and morphological operations. *Ind. J. Fib. Text. R.* 2014; 39, Sept: 254-259.
5. Karayiannis YA, Stojanovic R, Mitropoulos P. Defect detection and classification on web textile fabric using multiresolution decomposition and neural networks. In: *The 6th IEEE Int. Conf. on Elect. Circuits and Systems.* 1999; 2: 765 – 768.
6. Goswami MB, Datta KA. Detecting defects in fabric with laser-based morphological image processing. *Text. Res. J.* 2000; 70(9): 758-762.
7. Mak KL, Peng P, Lau HYK. A real-time computer vision system for detecting defects in textile fabrics. In: *IEEE Int. Conf. on Industrial Tech., Hong Kong, China*, 2005, pp. 469-474.
8. Han R, Zhang L. Fabric defect detection method based on Gabor filter mask. In: *Global Congress on Intell. Systems, Xiamen, China*, 2009: 184-188.
9. Cho CS, Chung BM, Moo-Jin P. Development of real-time vision-based fabric inspection system. *IEEE Trans. on Industrial Elect.* 2005; 52: 1073-1079.
10. Conci A, Proença CB. A comparison between image-processing approaches to textile inspection. *J. Text. Inst.* 2000; 91, 2: 317-323.
11. Hu MC, Tsai IS. The inspection of fabric defects by using wavelet transform. *J. Text. Inst.*, 2000; 91, 3: 420-443.
12. Mak KL, Peng P, Yiu KFC. Fabric defect detection using morphological filters. *Image Vision Comput.* 2009; 27: 1585–1592.
13. Furferi R, Governi L. Machine vision tool for real-time detection of defects on textile raw fabrics. *J. Text. Inst.* 2008; 99, 1: 57-66.
14. Çelik HI. *Development of an intelligent fabric defect inspection system.* University Of Gaziantep Graduate School Of Natural & Applied Sciences. Ph.D Thesis In Mechanical Engineering, 2013.
15. Çelik Hİ, Dülger LC, Topalbekiroğlu M. Developing an algorithm for defect detection of denim fabric: gabor filter method. *Teks ve Konf.* 2013; 23(2): 255-260.
16. Jain AK, Farrokhnia F. Unsupervised texture segmentation using Gabor filters. *Pattern Recognit.* 1991; 24(12): 1167–1186.
17. Porat M, Zeevi YY. The generalized Gabor scheme of image representation in biological and machine vision. *IEEE Trans. on Pattern Analysis and Mach. Intell.* 1988; 10: 452– 468.
18. Bovik AC, Clark M, Geisler WS. Multichannel texture analysis using localized spatial filters. *IEEE Trans. on Pattern Analysis and Mach. Intell.* 1990; 12, 1: 55–73.
19. Kumar A, Pang G. Fabric defect segmentation using multichannel blob detectors. *Opt. Eng.* 2000; 39(12): 3176-3190.
20. Grigorescu SE, Petkov N, Kruizinga P. Comparison of texture features based on Gabor filters. *IEEE Transactions on Image Processing* 2002; 11, 1: 1160 – 1167.
21. The MathWorks, Inc. Create predefined 2-D filter, http://www.mathworks.com/help/toolbox/images/ref/fspecial.html#bqkft1d (accessed 10 June 2012).
22. Sonka M, Hlavac V, Boyle R. *Image processing, analysis and machine vision international student edition*. 3rd. ed. Toronto, 2008: 661-665.
23. Solomon C, Breckon T. *Fundamentals of digital image processing a practical approach with examples in MATLAB.* Chichester, 2011: 200-202.
24. Mak KL, Peng P. Detecting defects in textile fabrics with optimal Gabor filters. *World Aca. of Sci. Eng. and Tech.* 2006; 13: 75-80.

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