Automatic Recognition of Fabric Weave Patterns by Digital Image Analysis

TAE JIN KANG AND CHANG HOON KIM

Department of Fiber and Polymer Science, Seoul National University, Seoul, Korea

KYUNG WHA OH

Department of Home Economics Education, Chung-Ang University, Seoul, Korea

ABSTRACT

By using computer image processing and analysis, a system to detect both weave patterns and yarn color designs is developed in this study. The image of a woven fabric is captured by a Hitachi color CCD camera and converted into digital data by a Targa+32 board. Two images—transmitted and reflected—are used to detect weave patterns. From the transmitted images, warp and weft cross points and the sizes of the yarns are determined by analyzing gray value changes in both horizontal and vertical directions. Then the warp and weft crossed states are determined by analyzing the normalized aspect ratio of an ellipse-shaped image at crossed points of the fabric. Furthermore, from reflected images, the total number of yarn colors and their arrangements in the fabric are determined. An HSV color model differentiates or groups similar yarn colors. Consequently, the system allows the weave pattern, either colored or solid, and the color design of a fabric to be correctly recognized.

Recent advances in computer technology in the textile industry have permitted process automation and automatic product quality monitoring as well as improved production speeds. Image analysis technology, which has rapidly developed since the 1960s, is especially useful in textile manufacturing and inspection, including texture evaluation and inspection of textile surface characteristics [2, 9, 15–17], analysis of cotton fiber maturity [14], characterization of nonwoven structures [4, 8], and evaluation of carpet aesthetic appearance [11, 12]. However, even though computer techniques are used in all these areas, the analysis of fabric weave structure still relies on human inspection. It is very tedious and time-consuming work, accomplished with a teasing needle with the naked human eye. Therefore, it has become necessary to develop artificial vision inspection and automation to analyze fabric weave structures, thus avoiding while providing fatigue better reliability and improved accuracy.

Fabric pattern recognition by image analysis has been studied since the middle of 1980s [6–10], but there are limits to its adaptability for solid fabrics, since this method recognizes patterns by light reflection from the warp and weft. In a solid fabric, the weave pattern is recognized by thinning processing and mosaic averaging of the systematic pattern of the bright parts, where sections of the float yarns exposed to the fabric surface turn bright and the interlacing points appear dark. It is therefore difficult to use this traditional method for a fabric composed of both bright and dark colored yarns, since the method depends on the pattern of the bright parts.

In this paper, we provide a recognition algorithm that can be applied to a fabric with different colored yarns as well as solid ones. Using this method, it is possible to obtain information on weave patterns and the arrangements of colored yarns independently, which means it is useful for almost all kinds of single-layer weave fabrics. For this purpose, we have developed a system for automatic recognition of weave patterns by image analysis, which can recognize weave patterns and arrangements of colored yarns in a fabric and generate structural parameters necessary for analyzing weave patterns. In the image processing system, noise and any inconsistencies in the image caused by nonuniform illumination are removed by Gaussian filtering and histogram equalization. Interlacing patterns of warp and weft yarns are recognized by analyzing gray levels at the crossed points. In addition, we differentiate the different colored yarns by comparing their H (hue) values after converting yarn color from an RGB (red, green, and blue) color model to an HSV (hue, saturation, and value) color model. Finally, fabric weave patterns are automatically recognized based on the detection of interlacing patterns, warp and weft densities, each yarn size, and the arrangement of yarn colors.

Major Image Processing Method

IMAGE CAPTURE

We captured images perpendicular to the focal plane of a Hitachi color CCD camera with a 12.5 - 75 mm zoom lens and a spatial resolution of 640 × 480 pixels, then displayed them in the color monitor through a frame grabber, digitized by the host computer, and stored in the main memory. Digitization was done on a Targa+32 bit capture card installed in a Pentium 90 Mhz PC. We developed this system with Windows 95 using Microsoft Visual C++ 4.0 as a software development tool.

There were two monitors in this system—one for confirming the captured image and the other for the image processing program. A fabric was illuminated by halogen bulbs mounted on the top of the sample, with transmitted bright field light provided by an overhead projector. The lights on the top of the fabric were used to analyze the weave pattern and arrangement of colored yarns. The lighting angle was adjusted to maximize the contrast in the image. Transmitted lights placed under the fabric were used to analyze the position of warp and weft yarns.

IMAGE PROCESSING

We used several techniques to process images for this study, including Gaussian filtering, thresholding, histogram equalization, and autocorrelation [3, 5, 13]. All images were filtered with a 5 × 5 Gaussian filter to remove the noise, then converted to binary images of black and white by selecting the mean gray level value as the threshold. Next we used the common morphological operation of erosion and dilation to reduce or increase the size of a white object within the fabric image. By successive operations of erosion, dilation, and opening processes, small undesirable pixels remaining in the image after the thresholding process were removed.

To reassign gray level values so as to produce a flattened histogram with a more uniform gray level distribution, we used histogram equalization to minimize the uneven distribution of gray levels of pixels caused by local illumination.

We used autocorrelation to determine structural repeat units in the fabric weave. The general autocorrelation functions in weft $C_{x,0}$ and warp $C_{0,y}$ directions are shown in Equations 1 and 2:

$$C_{x,0} = \sum_{i}^{M} \sum_{j}^{N} G_{i,j} G_{i-x,j} \quad , \tag{1}$$

$$C_{0,y} = \sum_{i}^{M} \sum_{j}^{N} G_{i,j} G_{i,j-y} \quad . \tag{2}$$

Here, $G_{i,j}$ is the gray level of a pixel (i,j) in an image, M and N are the number of pixels in weft and warp directions, and $C_{x,0}$ and $C_{0,y}$ represent peaks at integer multiples corresponding to the number of pixels comprising the average repeat unit size in each fabric direction. Figure 1 shows an example of autocorrelation of a fabric image. The fabric is illuminated by halogen bulbs mounted on the top of the sample, and the image

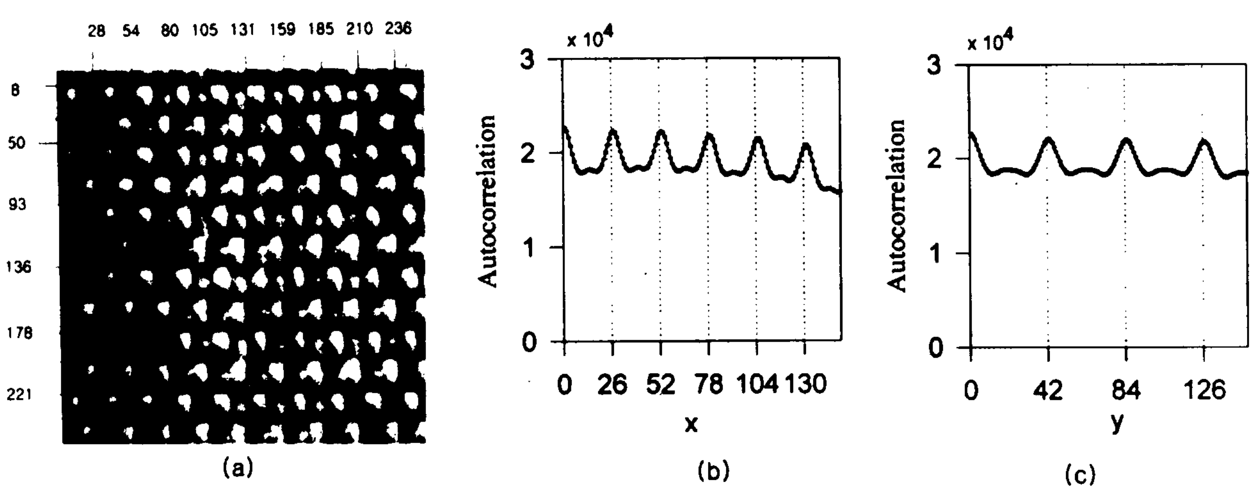

FIGURE 1. Autocorrelation of fabric image: (a) image of plain weave fabric, (b) weft-directional autocorrelation, and (c) warp-directional autocorrelation.

is captured perpendicular to the focal plane of the CCD camera. Figure 1a illustrates a histogram equalized image and Figures 1b and 1c present the results of autocorrelation of the image in the weft and warp directions, respectively. As a result, autocorrelation maxima appear at intervals of 24 pixels in the weft direction and 42 pixels in the warp direction, and the normal repeat unit for this fabric becomes 42 × 24.

Automatic Recognition of Weave Pattern

BASIC CONCEPT

When simplifying the weave pattern of all fabrics, there are only two possible states in which the warp is interlaced over the weft or vice versa. Therefore, we expected it would be possible to recognize all kinds of weave patterns if we could detect whether the warp was interlaced over the weft or the weft was over the warp at the crossed points with image analysis. In addition, we also expected that it would no longer be a problem if a fabric contained colored yarns, so long as we could determine the color of the floating yarns.

We proceeded in this project in three steps, with the basic concept as mentioned above: to detect warp and weft crossed points, to detect warp and weft crossed states at all crossed points, and to detect yarn colors at all crossed points. We used two images, transmitted and reflected, to detect weave patterns, and analyzed the yarn positions from the transmitted images. From the reflected image, we obtained the data for warp and weft interlacing and the arrangement of colored yarns.

DETECTING WARP AND WEFT CROSSED POINTS

Figure 2a is an example of a fabric image in transmissive illumination. In this image, the dark areas indicate the location of warp and weft yarns and the bright spots represent the spaces between interlacing yarns since light cannot be transmitted through the yarns. Accordingly, in the gray profile image illustrated in Figure 2b, the minima represent the locations of warp and weft yarns. Thus, we enhanced the bright part after Gaussian filtering and thresholding the transmissive lighted image, and found the positions of white pixel objects in order to detect the warp and weft crossed points. Then we connected the center coordinates of the white pixels horizontally and vertically and made a grid, as shown in Figure 3. We removed undesirable error lines formed by noise that was not filtered by image processing and connected missing lines based on the pattern of the regularity of interlacing points determined from the frequency histogram of the intervals between the white pixels. Finally, we obtained

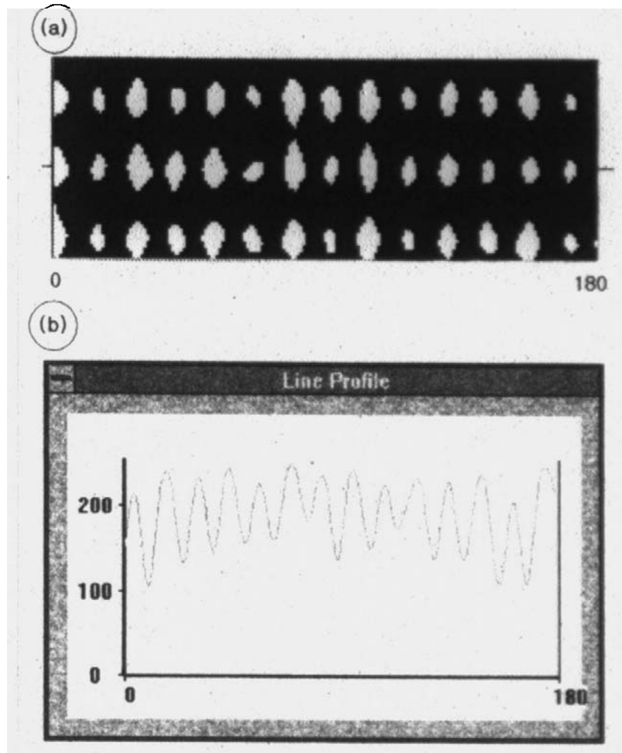

FIGURE 2. Enlarged image of fabric in transmissive illumination (a) and gray profile of image (b).

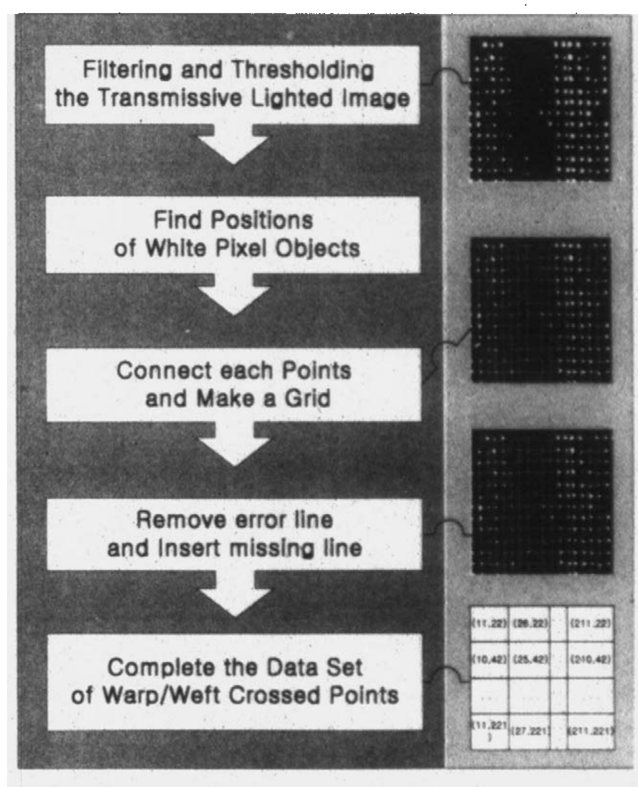

FIGURE 3. Flowchart of automatic detection of warp and weft positions.

the complete data set of warp and weft crossed points. With this process, we could measure the width and the number of warp and weft yarns within the image from the intervals between the horizontal and vertical lines. The fabric has to be placed carefully, since appropriate alignment of yarns parallel and perpendicular to the image axes is necessary for this algorithm to work properly.

DETECTING WARP AND WEFT CROSSED STATE

The flow chart for automatic detection of the warp and weft crossed states is outlined in Figure 4. We used the height-to-width ratio of an ellipse-shaped image to detect the warp and weft crossed state. In the enlarged image of the crossed point shown in Figure 5a, there are two kinds of floating yarn image where the height is greater than the width or vice versa. When the aspect ratio is greater than 1, the warp is over the weft and vice versa. Therefore, we have obtained the warp and weft interlacing data by analyzing the aspect ratio of the ellipse-shaped image at the crossed points. The aspect ratio (AR) is defined in Equation 3:

$$AR = H/W \quad , \tag{3}$$

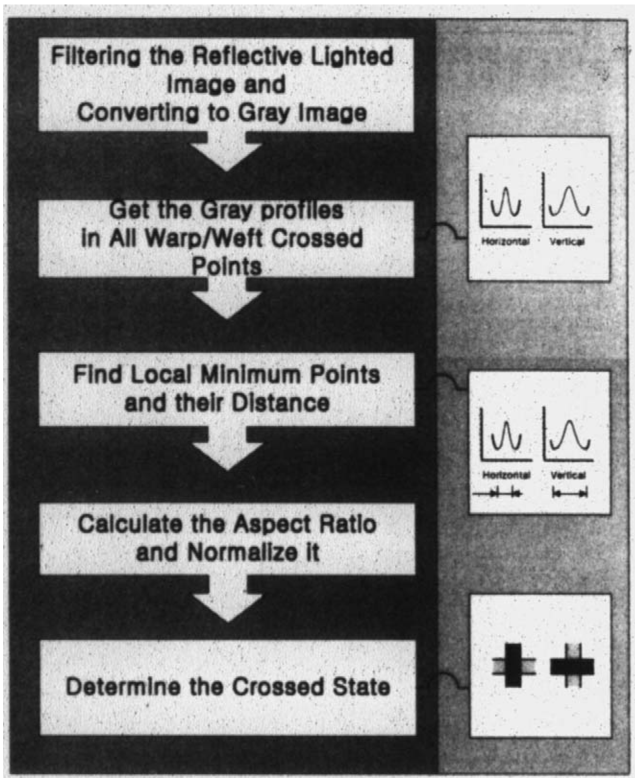

FIGURE 4. Flowchart of automatic detection of warp and weft crossed state.

where W is the width and H is the height of the ellipse-shaped image.

We determined the aspect ratio of an image at the warp and weft crossed point by measuring the local minimum distance between minima in the vertical and horizontal gray profiles, as illustrated in Figure 6. In practical application, we found that the aspect ratio of the ellipse-shaped image was sometimes greater than 1, even though the weft crossed over the warp in such a way that the warp width was finer than the weft, as shown in Figure 5c. Therefore, we modified the equation and used Equation 4 to calculate the normalized aspect ratio with the width of the warp and weft, which is equivalent to yarn size. We determined warp and weft yarn widths from the transmitted image by measuring the intervals between the horizontal and vertical lines, as shown in Figure 3:

$$AR' = H'/W' \quad , \tag{4}$$

where W' = the width of the ellipse-shaped image/width of warp, and H' = the height of the ellipse-shaped image/width of weft.

AUTOMATICALLY DETECTING YARN COLOR

A flow chart for automatically detecting yarn color is shown in Figure 7. It was often the case that 2^{24}

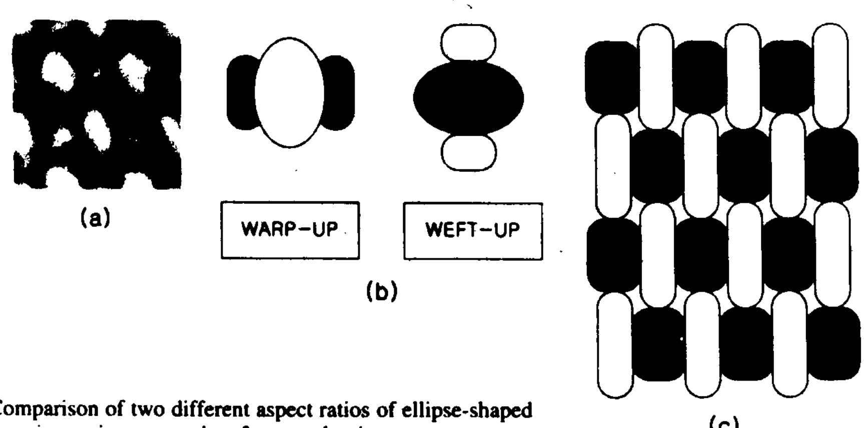

FIGURE 5. Comparison of two different aspect ratios of ellipse-shaped image in warp and weft crossed point.

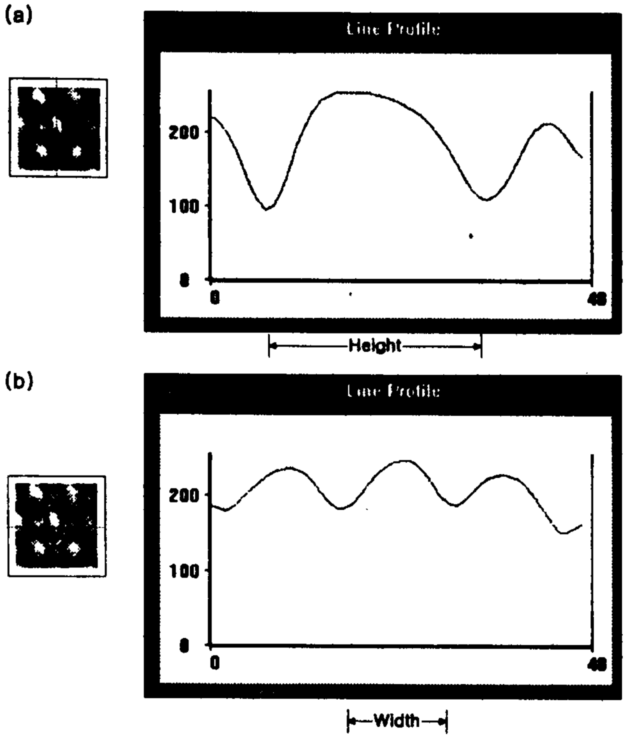

FIGURE 6. Determination of aspect ratio of ellipse-shaped image at warp and weft crossed points by local minimum distance in gray profiles: (a) vertical profiles and (b) horizontal profiles.

colors appeared in the fabric color image (true color image) captured by the CCD camera, even though only a few colors existed in the real fabric. Therefore, it was important to reduce the number of colors in the fabric image by selecting only meaningful colors. After Gaussian filtering the reflective lighted image to minimize the effect of hairiness, we converted the true color image to a reduced 256 colors by octree quantization, detailed elsewhere [1]. We then determined the high frequency color index number at all warp and weft crossed points. Through this process, we detected seven to eight colors in a fabric composed of one or two colored yarns.

In the next step, we converted the recognized yarn colors from RGB values to HSV values in order to group similar colors, then determined the total number of yarn colors. Among the recognized fabric colors, several that were recognized as different colors in the RGB color model, but turned out to be similar to an H value in the HSV color model, were assigned to the same color. Through this mapping process, the total number of yarn colors in the fabric could be almost precisely determined. Finally, by investigating the connection of the recognized colors within the fabric, we determined whether they were stripes or noise or repeated with the weave pattern. Then we updated the mis-detected colors and obtained the complete yarn color data.

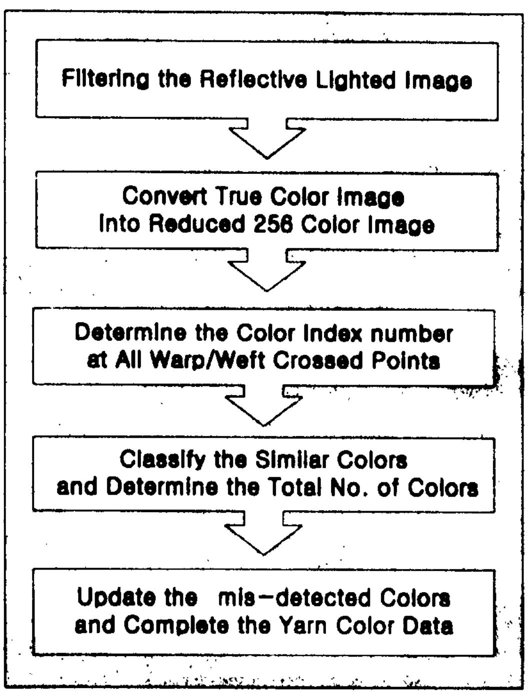

FIGURE 7. Flowchart of automatic detection of yarn color.

Results

We applied our automatic detection system for fabric weave patterns to solid or colored plain weave fabrics. Figures 8 and 9 show examples of the system output. As a result, it was possible to detect and correctly classify the weave patterns of fabrics with several different colored yarns as well as solid color fabrics. The sample image used in this study appeared on the left side, and the recognized weave pattern was on the right side of the output screen. Color arrangements of weft and warp are illustrated on the left and bottom of the weave pattern. Automatically recognized fabric weave patterns appear on the center of the screen based on the detection of interlacing patterns, weft and warp density, each yarn size, and the color arrangements. Alternatively, it is also possible to design fabrics using the information on yarn and fabric characteristics described above with this system.

Figure 8 shows the results of automatic detection of the weave pattern and yarn color design for a plain weave fabric with two-tone colors, and Figure 9 shows results for a twill weave fabric with a one-tone color. Overall, we found that both fabric weave pattern and color design can be analyzed successfully using our

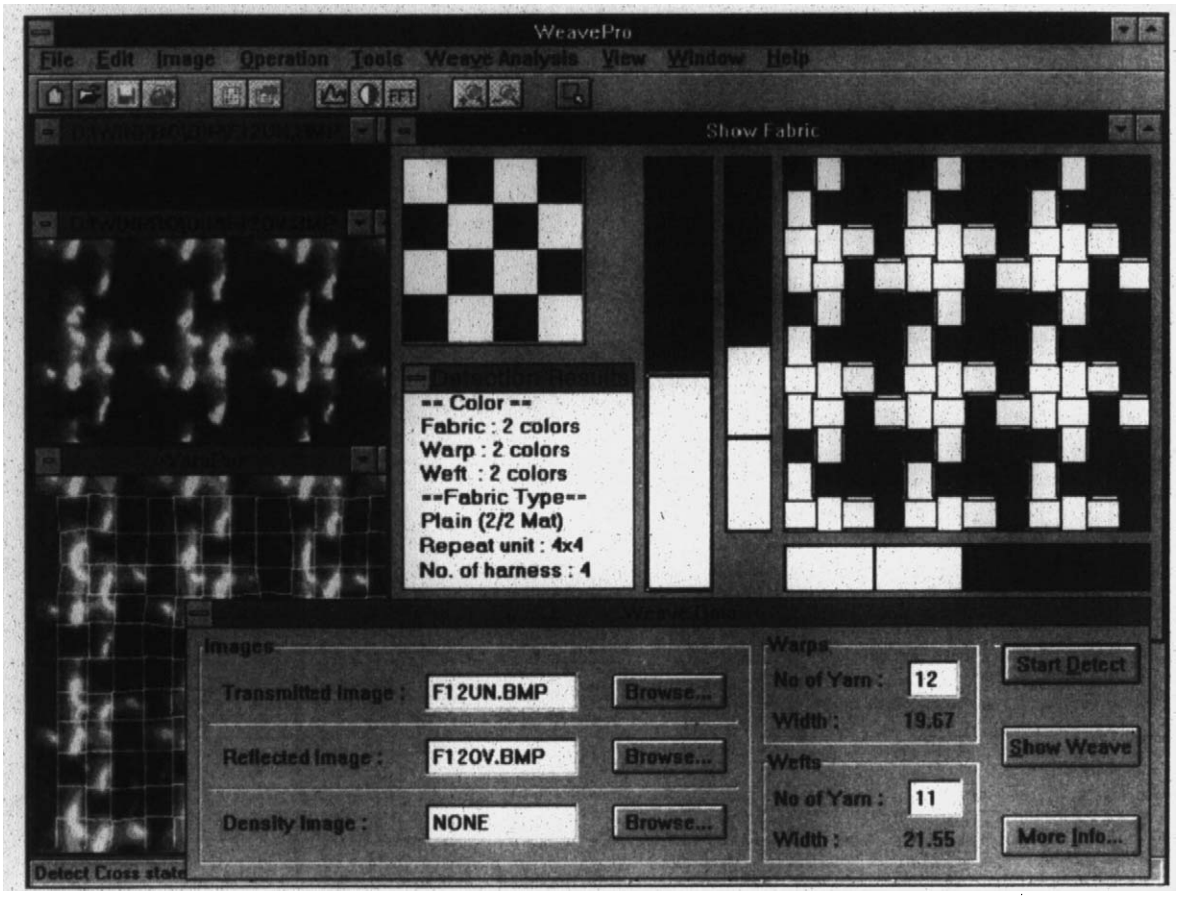

FIGURE 8. Results of automatic detection of weave pattern and yarn color design for a plain weave fabric with a more complicated pattern and two-tone colors.

automatic recognition system. With a Pentium 90 Mhz computer, it takes about 33 seconds for total detection after capturing the fabric image.

Conclusions

We have developed a system to detect weave patterns and yarn colors by digital image analysis. The image of woven fabric is captured by a Hitachi color CCD camera and converted into digital data through a Targa+32 board. Two images, transmissive and reflective, are used to detect weave patterns. From the transmitted image, warp and weft crossed points are detected by analyzing the gray profile in both horizontal and vertical directions, then the warp and weft crossed states are determined by analyzing the normalized aspect ratio of an ellipse-shaped image at a crossed point. The reflecting image yields warp and weft interlacing data and the arrangements of yarn colors. After Gaussian filtering the reflective lighted image to minimize the effect of fabric hairiness, we can convert the true color image to a reduced 256 colors with octree quantization. The HSV color model groups similar yarn colors and determines the total number of yarn colors. Finally, fabric weave patterns are recognized with the complete set of information on the warp and weft crossed points, crossed states, and arrangements of yarn colors. Overall, we have shown that fabric weave pattern and color design can be analyzed successfully using the automatic recognition system developed in this study. This technique may have general applicability to pattern analysis of colored and patterned fabrics as well as solid ones. However, its use is limited to single layer weaves and would not work for complex fancy fabrics of more than one layer.

Literature Cited

1. Ahn, B. S., "Computer Darkroom Made of C," Saehwa Press, Korea, 1994.
2. Convey, S., Hashim, A.; and McGinnity, M., Automated Fabric Inspection, *Int. J. Clothing Sci. Technol.* **6**(5), 15–18 (1994).
3. Doughhety, E. R., and Giardina, C. R., "Matrix Structured Image Processing," Pretice Hall, NJ, 1987.

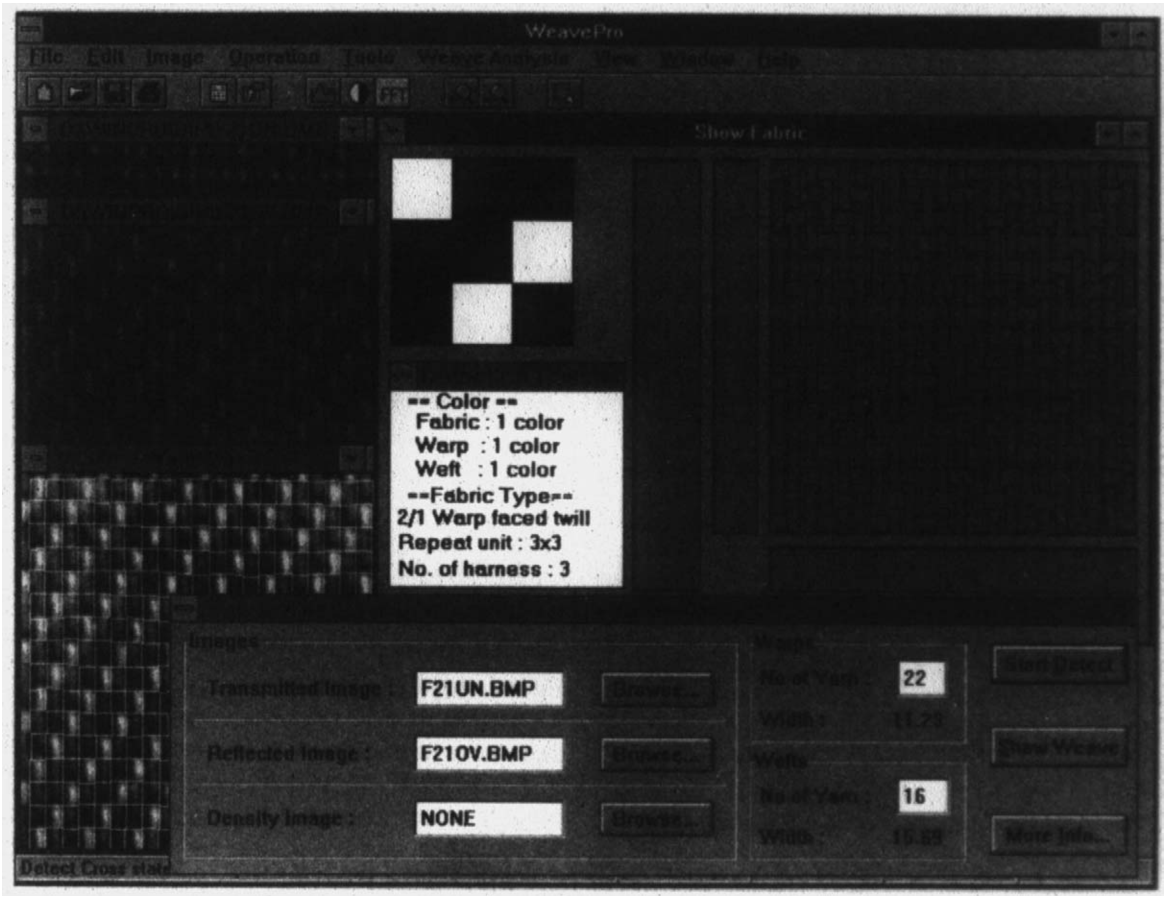

FIGURE 9. Results of automatic detection of weave pattern and yarn color design for a twill weave fabric with one-tone color.

4. Huang, X. C., and Bresee, R. R., Characterizing Nonwoven Web Structure Using Image Analysis Techniques, Part I: Pore Analysis in Thin Webs, *INDA J. Nowovens Res.* **5**(1), 13–21 (1993).
5. Jain, A. K., "Fundamentals of Digital Image Processing," Prentice Hall, NJ, 1989.
6. Kinoshita, M., Hashimoto, Y., Akiyama, R., and Uchiyama, S., Determination of Weave Type in Woven Fabric by Digital Image Processing, *J. Textile Mach. Soc. Jpn.* **35**(2), 1–4 (1989).
7. Lin, H. C., Rapid Fabric Weave Analysis Method by Computer Image Processing, in "Proc. 2nd Asian Textile Conf., Korea," Vol. 1, 1993, pp. 317–320.
8. Na, Y., Pore Shape Characteristics of Aramid and Simulated Nonwoven Fabrics through Image Analysis, *J. Kor. Fiber Soc.* **33**(11), 939–946 (1996).
9. Nishimatsu, T., Automatic Recognition of the Interlacing Pattern of Woven Fabrics, *J. Textile Mach. Soc. Jpn.* **44**(6), 51–57 (1991).
10. Ohta, K., Sakaue, K., and Tamura, H., Pattern Recognition of Fabric Surfaces, *J. Textile Mach. Soc. Jpn.* **32**(1), 7–10 (1986).
11. Pourdeyhimi, B., Xu, B., and Sobus, J., Evaluating Carpet Appearance Loss: Surface Intensity and Roughness, *Textile Res. J.* **63**(9), 523–535 (1993).
12. Pourdeyhimi, B., Xu, B., and Wehrle, L., Evaluating Carpet Appearance Loss: Periodicity and Tuft Placement, *Textile Res. J.* **64**(1), 21–22 (1994).
13. Simon, J. C., and Rosenfield, A., "Digital Image Processing and Analysis," Noordhoff International Pub., Netherlands, 1977.
14. Thibodeaux, D. P., and Evans, J. P., Cotton Fiber Maturity by Image Analysis, *Textile Res. J.* **56**(2), 130–139 (1986).
15. Xu, B., and Reed, J. A., Instrumental Evaluation of Fabric Wrinkle Recovery, *J. Textile Inst.* **86**(1), 129–135 (1995).
16. Youk, Y. S., "Basic Fabric Weave Construction," Dongmyung Press, Korea, 1991.
17. Zhang, Y. F., and Bresee, R. R., Fabric Defect Detection and Classification Using Image Analysis, *Textile Res. J.* **65**(1), 1–9 (1995).

Manuscript received September 29, 1997; accepted December 30, 1997.