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Automatic Identification of Weave Patterns of Checked and Colored Fabrics Using Optical Coherence Tomography

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Abstract: Identifying the weave pattern of fabrics can be done manually or automatically. Carrying out the weave recognition automatically will reduce the procedure time and error rates since automatic systems can perform successive measurements at high speeds and with great repeatability and quality. Woven fabric repeat identification systems that are automatic, usually work by employing complex algorithms and techniques. It is known that these automatic techniques struggle when trying to identify highly complex patterns, composing of a combination of different structures, figures, and colors. For example, image processing algorithms are known to make errors when dealing with checked and colored fabrics. In this paper, we apply the spectral domain optical coherence tomography imaging technique for identifying checked and colored woven fabric repeat automatically. This is achieved by employing an in-house written JAVA code that extracts the weave pattern from the tomography images. We show that automatic identification of weave pattern of checked and colored fabrics can be performed nondestructively by employing optical coherence tomography.

Index Terms: Optical coherent tomography, instrumentation.

1. Introduction

The weave itself plays an important role in the quality of the fabric since both the physical and aesthetic aspects of a fabric are directly determined by the weave structure [1].

In the textile industry traditionally weaving has been used to produce a fabric by interlacing two separate sets of yarns perpendicular to each other. It is crucial to have the interlacing of the warp and weft of the yarns in a special way that makes the fabric not only strong and stable, but also visually aesthetic. The pattern in which the warp and weft yarns are weaved together by passing over and under each other determines the weave repeat. The fabric is then composed by the recurrence of the weave repeat. Therefore the weave structure has a periodicity that is the same as the weave repeat size. Marked squares and blank squares on point paper are used to represent the weave structure of fabrics. The weft and warp yarns are simply represented by the horizontal and vertical spaces located on the point paper. The position where one warp intersects with one weft yarn is indicated by a square on the point paper. A marked square is placed when warp passes over weft, a blank square is used when the weft passes over the warp.

It is crucial to identify the weave repeat of woven fabrics at yarn level before the fabric is produced. Humans with the aid of pins can perform the identification task manually by scrutinizing the fabric with their eyes. The human factor however makes the identification carried out subjective and error prone. In addition to being biased the manual procedure is tedious and therefore not desired [2]. As a means to remove the human factor many researchers have looked into identification of the weave pattern automatically via image processing technology. Extensive research efforts began in the early 1980s in order to automate the weave identification task. Early systems could identify weave patterns by taking images of the fabric and performing clever algorithms on the images [3], [4]. Lachkar *et al.* [5], who applied the Fourier image-analysis algorithm to identify crossed-points in woven fabrics, used this information in analyzing different fabrics [6]. A new approach made use of Wiener filters applied to digital image processing in the recognition of the fabric structure [7]. Another research team realized the automatic weave pattern detection by utilizing morphological operations to enhance the gray scale image of a weave repeat that was achieved by scanning [8]. More complex algorithms such as the fuzzy C-means (FCM) algorithm, BP neural network and white-black co-occurrence matrix methods were also applied to identify the woven fabric pattern via image recognition techniques [9]. Further detection algorithms used in pattern detection include the Gabor wavelet, local binary pattern operators and gray-level co-occurrence matrices (GLCM) techniques [10]. For example plain and twill weave patterns were identified successfully by the use of wavelet transform, Radon Transform and Learning Vector Quantization, which measured fabric texture orientations [11]. Another research team identified fabric patterns by evaluating the autocorrelation at every pixel in the equalized images in colorless patterns [12]. Xiao *et al.* identified weave pattern automatically by applying the gray projection curves, the gradient histogram feature and improved FCM algorithm together [13]. Zheng took advantage of the characteristics of corner information and second-order statistics, to analyze the repeat size and identify the pattern [14]. Another team exploited the improved distance matching function (IDMF) to identify the weave repeat [15].

By combining more than 100 2D microtome images of yarn sections created a virtual 3D multi-filament woven fabric [16]. A special software program was used to restore the individual microtome images digitally in their specific locations. Very recently a 2D FFT algorithm was applied to recognize weave patterns [17].

Especially frequency based analysis methods are known to be not suitable when applied to the recognition of multicolored and textured fabrics [3]. We apply the optical coherence tomography (OCT) imaging method in identifying the weave pattern of checked and colored fabrics.

OCT is an imaging method that infers surface characteristics through low coherence interferometry. OCT facilitates highly sensitive non-contact and non-destructive measurements making it an ideal candidate for automated inspection systems [18], [19].

OCT has been also applied to textiles to study the various types of polymers and composites subjected to different treatments and effects [20]–[25]. OCT was also successfully used in the recognition of weave patterns of woven fabrics that are uni colored [26]. We extend this study further by applying the method to checked and colored fabrics and by employing the image analysis automatically by a written software code.

Identification of weave pattern of checked and colored patterned fabrics by image processing methods have not yet been successfully performed until date, because of the difficulties involved in the analysis. We took advantage of the special properties of OCT in the automatic identification of the weave patterns of checked and colored patterned woven fabric. In our study we scanned an infrared light beam having 930 nm wavelength over checked and colored patterned woven fabrics in order to take OCT images non-destructively and non-contactly. An in-house JAVA program then extracted the weave pattern automatically from the OCT images.

2. Experiment

In this study, two different fabrics, whose photos are given in Fig. 1 were scanned with OCT in order to identify their weave patterns.

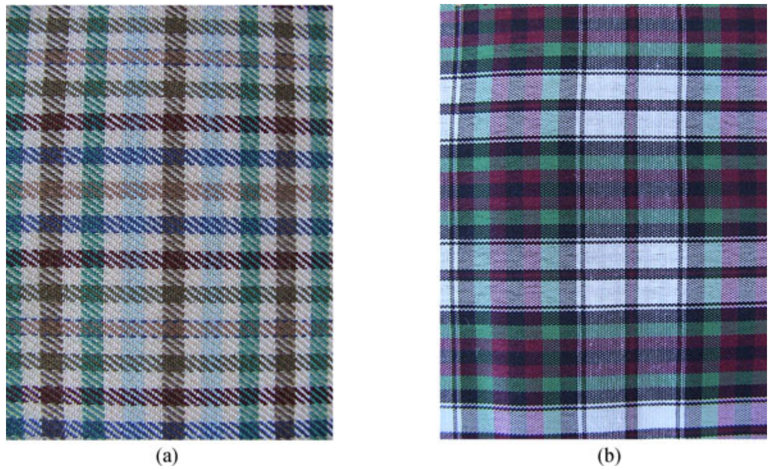

Fig. 1. Images of the checked and colored patterned woven fabric samples. (a) 2/2 twill woven fabric. (b) Plain woven fabric.

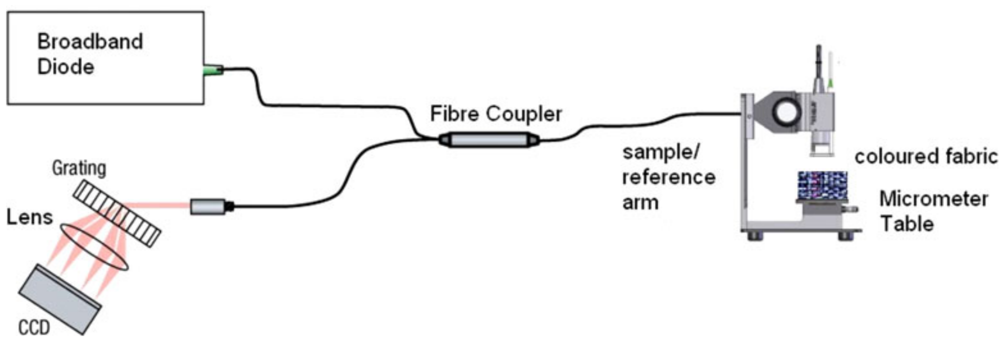

Fig. 2. Experimental setup.

2.1 Optical Coherence Tomography of Woven Fabrics

In Fig. 2, we give the experimental scheme used for the OCT scan of the woven fabric. The broadband diode produces an infrared light beam at 930 nm with a 100 nm bandwidth [27]. The broadband nature of the light enables imaging with low speckle noise [28]–[30]. The light waves reflected off the sample and reference arms interfere in the fiber coupler. The interference signal is then decomposed into individual frequency components by an optical grating. Every frequency constituent is collected by an optical lens and registered by the Charge Coupled Device (CCD). The colored and checked fabric to be measured was placed in the sample/reference arm of the interferometer. Photons with a central wavelength of 930 nm are directed from the broadband diode onto the fabric surface given in Fig. 2. This relatively short source wavelength allows for high resolution scans. The OCT signal is generated by scanning the light beam over the surface. The Fourier Transform of this signal results in the A-scan image of the sample. By combining a concatenation of A-scan images created along the transverse plane of the fabric, the B-scan is made. Further information on the OCT theory can be found in the following reference [31]. The A-scan line rate was 1.2 kHz and B-scan frame rate was equal to 512 lines/frame. The average imaging depth was 1.7 mm. The resolution of the OCT image was approximately 10 μm.

2.2 The OCT Measurement Procedure

The checked and colored fabric whose weave pattern is to be identified is put on a table with micrometer adjustment in the sample/reference arm as shown in Fig. 2. The sample arm length is

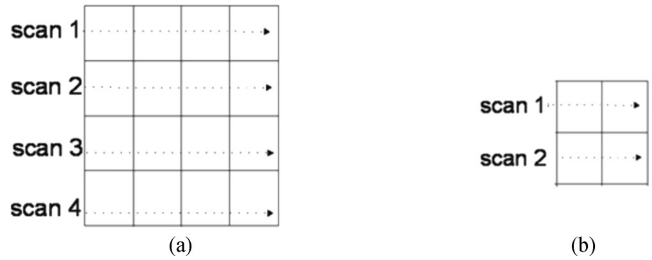

Fig. 3. Measurement procedure: OCT scans, necessary for (a) 2/2 twill and (b) plain weave patterns.

arranged by monitoring the signal reflected of the fabric-air interface such that the infrared beam from the broadband diode was focused on the fabric. Getting a clear image on the CCD camera and receiving an OCT scan within the average imaging depth allows for a proper measurement of the fabric. From above the fabric, the beam then traverses over the warp and weft regions of the fabric sequentially along the warp direction. In order to identify the weave repeat of the fabric the measurement procedure is repeated after shifting the beam orthogonally by an amount equal to the yarn diameter. The scanning process is repeated until the periodicity of the signal and then the weave repeat can be identified. The measurement principle was outlined in a recent publication [26]. For the 2/2 twill weave pattern, the periodicity will be four, meaning that after four scans the OCT will repeat itself, rendering four scans sufficient (Fig. 3). The OCT signal will record the reflection characteristic of the surface which the beam interacts with, hence revealing information about the weave pattern. Because the warp and weft regions have their own unique OCT signals, the scan profile allows for a weave pattern identification. Four successive OCT measurements are required to identify a fabric that has 2/2 twill weave pattern. For a fabric with plain weave pattern, two measurements will suffice since the periodicity of the weave matrix is equal to two.

3. Results and Discussions

In Fig. 4, the OCT images corresponding to four successive scans of the checked and colored fabric sample are given. The top region of the OCT images is black since before the beam interacts with the fabric, it travels in air where no strong reflections can occur. The y axis represents the penetration into the fabric, and the x-axis represents the scanning across the fabric surface. White regions of the scan reveal the abrupt index of reflection change resulting in the back reflections. Therefore the OCT image gives important information regarding the surface profile and characteristics of the fabric. The images are analyzed via a computer program written in JAVA. From the OCT scan it is trivial to distinguish two different reflecting surfaces and also infer the periodic change in the profile height. In a region where the warp goes over the weft the OCT scan has a higher profile and shows different reflection characteristic than in the region where the warp goes below the weft. Therefore the peaks of the OCT scan indicate weave regions where warp passes over weft. The computer code unravels this information. Similarly the dips of the OCT scan are the fabric regions where warp passes under weft. The measurements verify that the warp and weft regions of the fabric have two distinct reflection characteristics. This information is then used by the computer code in the reconstruction of the weave matrix and identification of the weave pattern. In order to perform the identification the OCT image is partitioned into areas with a width equal to the yarn diameter. The procedure is performed automatically by an in-house written JAVA software code. The user interface and an image analysis output is presented in Fig. 5. The program takes the OCT scan images and partitions it into vertical areas with a width equal to the yarn diameter. Then, average height values of pixels that have an intensity value over a determined threshold are calculated. The OCT scan image is grayscale and the intensity values lie in a range of 0–255. Since OCT scan generates black tones where there isn't any strong reflection and since the actual reflection from the textile generates tones of white, the threshold for the intensity is chosen to be 126. Pixels having higher intensity values than this threshold are considered to be part of

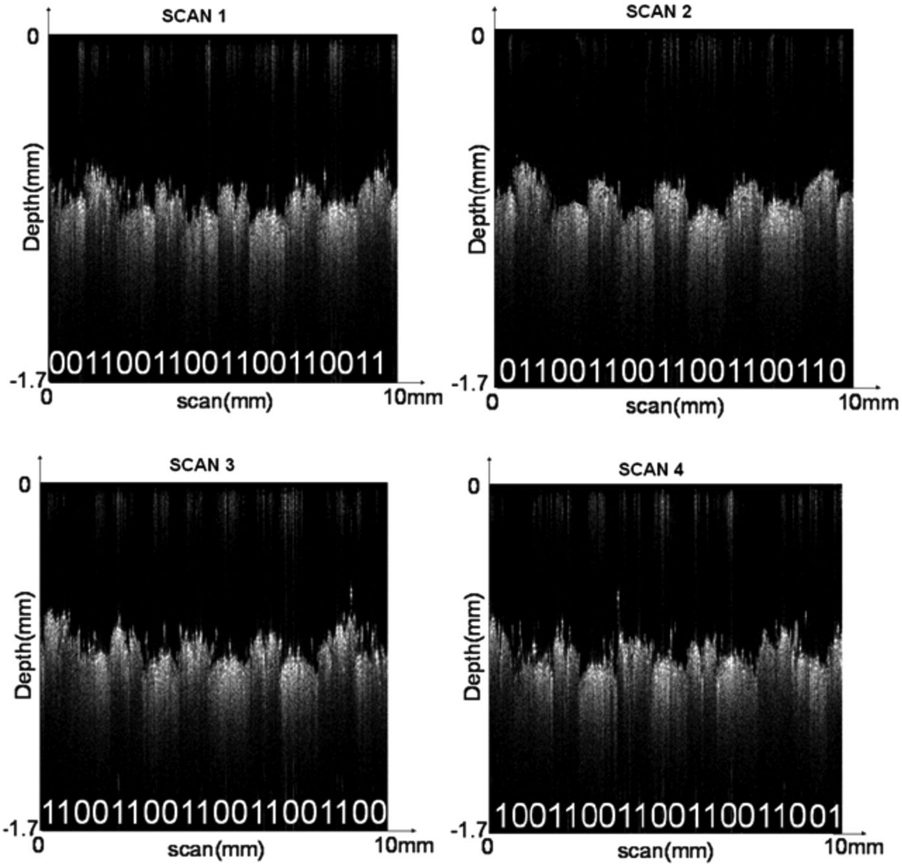

Fig. 4. OCT images that are taken from scan 1, scan 2, scan 3 and 4 over the first fabric. The OCT scan reveals the different reflection characteristics of the surface.

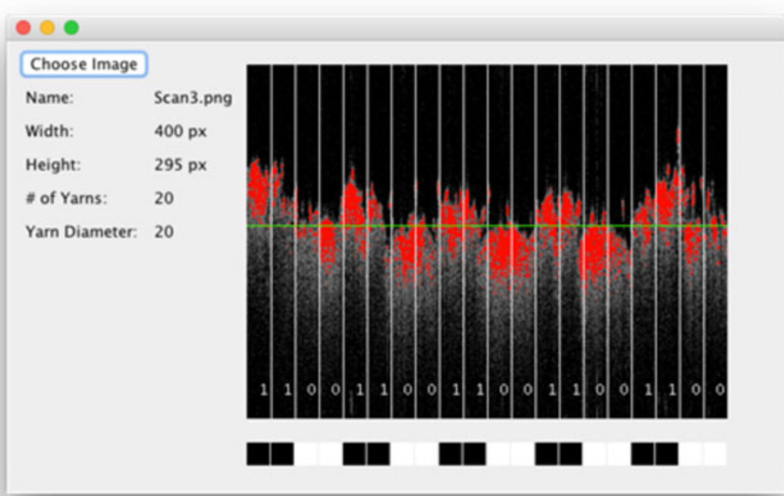

Fig. 5. User Interface view of the software with the inferred binary weave data.

The Weave Matrix

0	0	1	1
0	1	1	0
1	1	0	0
1	0	0	1

Weave Pattern

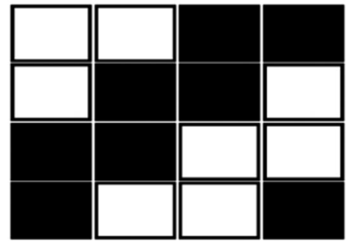

Fig. 6. The weave matrix was generated from the four successive OCT scans corresponding to 2/2 twill weave pattern.

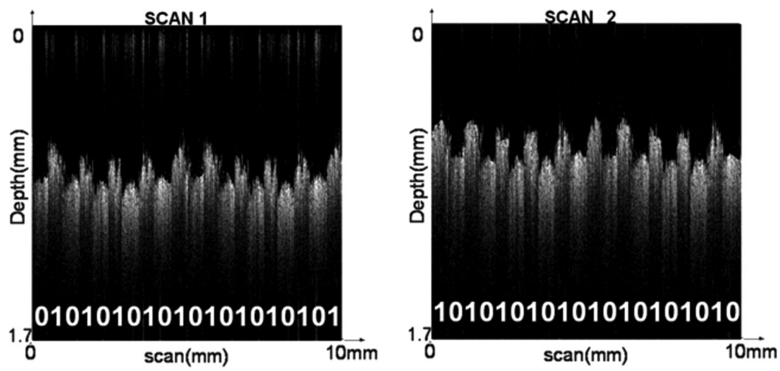

Fig. 7. The weave matrix was generated from the four successive OCT scans corresponding to 2/2 twill weave pattern.

Corresponding Weave Matrix

0	1
1	0

Weave Pattern

Fig. 8. The weave matrix was generated from the four successive OCT scans corresponding to 2/2 twill weave pattern.

the yarn that forms the air-cloth interface. These points are colored in red as given in the Fig. 5. The average height of the chosen pixels is drawn onto the image as a green line, representing the average profile height. Then the computer code marks a region with “1” if it is higher than the average profile height and ”0” if it is lower. These two regions have different reflection characteristics and therefore correspond to different regions of the weave. All places marked automatically with “1” correspond to where the warp is above the weft. Similarly a region is marked with a ”0”, if the warp yarn is below the weft. This scan hence gives us the profile of the weave and its periodicity. By combing successive scans the weave matrix is automatically generated. From the actual OCT scan the periodicity of the pattern is found to be equal to four, which means that identification of the weave repeat will require four OCT scans. The weave matrix and weave pattern inferred from the checked and colored fabric sample 1 is given in Fig. 6.

The same experiment is performed for another fabric sample also. The photo of this fabric was given in Fig. 1(b). The OCT scans of this fabric reveal a periodicity of two. The automatically extracted weave pattern corresponds to a plain weave structure. The OCT scan images are given in Fig. 7, and the corresponding weave matrix and weave pattern are included in Fig. 8. The weave pattern extraction procedure is exactly the same as explained earlier for sample A.

We conclude that the OCT photonic imaging modality can in principle be applied to the identification problem of weave patterns of checked and colored fabrics. The OCT scan measures differences in the refractive index of the material which makes the method color independent. The method is non-contact and non-destructive and can achieve high accuracy within the limitations of the imaging system. Because the OCT images are used to reconstruct the weave matrix and identify the weave pattern, the method will work for fabrics that have a thread diameter larger than 10 μm. The method will fail for other fabrics due to the fact that OCT cannot resolve structures smaller than 10 μm. Since OCT is color independent we conclude that the method is feasible for weave pattern detection on textiles that are checked and colored.

4. Conclusion

Automatic weave identification will reduce the procedure time and error rates since automated systems can perform successive measurements at high speeds and with great repeatability and quality. Woven fabric repeat identification systems that are automatic usually work by employing complex algorithms and techniques. It is known that these automatic techniques struggle when trying to identify highly complex patterns, composing of a combination of different structures, figures and colors. For example image processing algorithms are known to make errors when dealing with checked and colored fabrics.

The spectral domain optical coherence tomography imaging technique was applied for identifying checked and colored woven fabric repeat automatically. It was shown that automatic identification of weave pattern of checked and colored fabrics can be performed non-destructively by employing OCT. Weave pattern extraction from the tomography was accomplished by an in-house written JAVA program.

In this study, OCT scan images were utilized to recognize commonly used 2/2 twill and plain weave patterns of checked and colored woven fabric automatically. The method was quick and successful due to the color independence and high resolution of the OCT imaging, which proves that the technique can be used for the automatic identification of weave patterns of checked and colored fabrics. These traits make the adoption of the method in automatic inspection systems in the textile industry feasible.

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