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Recognition of Weave Patterns of Striped Fabrics Using Optical Coherence Tomography

DOI: 10.5604/01.3001.0011.7311

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Abstract
The recognition of woven fabric repeat by conventional techniques is labour intensive. In general, woven fabric repeat identification is accomplished automatically by employing complex algorithms and techniques. These algorithms may, however, occasionally fail, especially when dealing with high complexity texture patterns, structures, figures and colours. Optical coherence tomography (OCT) has the capability of taking high resolution images via contactless measurements. In this paper we apply the spectral domain optical coherence tomography imaging technique for identifying striped woven fabric repeat automatically. OCT scans corresponding to four different fabrics, from which the weave matrixes were recognised, are reported in this study. Automatic identification of weave patterns of striped fabrics was accomplished non-destructively by employing optical coherence tomography.

Key words: *optical coherence tomography, striped weave patterns recognition, woven fabric, plain weave, twill weave.*

Introduction

Quality may be simply defined as the degree that a certain product meets the demands of the user or consumer. The demands of textile consumers can vary a lot in the case of textile goods. The customer, for example, expects certain mechanical properties and aesthetic requirements that are determined by the chemical properties of fibres. The weave of the fabric affects the physical properties as well as some of the aesthetic aspects [1].

Weaving is an old method and kind of art used in textile manufacturing, in which two distinct sets of yarns interlace at right angles to make up a fabric. In order to have a fabric that not only has a stable and uniform structure but also looks aesthetic, the warp and weft of the yarns are interlaced with each other in a specific manner. The weave unit or weave repeat is determined by a manner in which warp and weft yarns are interlaced together by passing over and under each other. The fabric is formed by the repetition of the weave unit. Hence the weave structure shows a periodicity that is identical to the weave repeat size. The weave repeat of fabrics is denoted by marked squares and blank squares on point paper. The horizontal and vertical spaces located on the point paper serve as the weft and warp yarns, respectively. The location at which one warp intersects with one weft yarn is denoted by a square on the point paper. If in this region the warp passes over weft, the square is marked, while if the weft passes over the warp, then the square is left blank.

A vital step to take into consideration before producing the fabric is the identification of the weave pattern of woven fabrics at yarn level. Identification, carried out in a textile laboratory, relies on human vision and is performed with the help of pins, which makes the pattern recognition procedure subjective and prone to error. Moreover this manual method is time consuming and undesirable, because the efficiency depends largely on the knowledge and experience of inspectors [2]. In order to improve the quality and efficiency of textile and apparel production, many researchers have attempted to identify the weave pattern automatically by means of image processing technology.

Starting from the 1980s, scientists concentrated on developing algorithms specifically for weave pattern analysis and on creating equipment that automatically extracted images of fabrics [3]. Lachkar *et al.* [4] first used Fourier image-analysis techniques to detect crossed-points in woven fabrics. Later Lachkar *et al.* [5] used the crossed-states detected in determining fabric types. Shady *et al.* [6] developed a digital image processing approach to recognise the weave pattern utilising a Wiener filter. Another research group used digital image processing with Wiener filtering tailored to fabrics in order to recognise the fabric structure [7]. Ajallouian *et al*. [8] automatically detected the weave pattern by making use of morphological operations to enhance the gray scale image of a weave repeat that was obtained by scanning. Another research group applied the fuzzy C-means (FCM) algorithm, BP neural network and white–black co-occurrence matrix methods in order to determine the woven fabric pattern from the recognition results [9]. The weave patterns of woven fabrics were detected by Salem and Nasri [10] through combining the Gabor wavelet, local binary pattern operator and gray-level co-occurrence matrix (GLCM) techniques in their detection algorithm. Shen *et al.* [11] suggested using the wavelet transform, Radon Transform and Learning Vector Quantization for measuring fabric texture orientations and recognizing plain and twill weave patterns. Potiyaraj [12] recognised plain, twill and satin fabrics by analysing the autocorrelation at every pixel in the equalised images in patterns that had no colour. A combination of gray projection curves, the gradient histogram feature and improved FCM algorithm were used recently by Xiao [13] to automatically recognise woven fabric pattern. The characteristics of corner information and second-order statistics of fabric images were suggested by Zheng [14] in order to analyse the repeat size and identify plain, satin and twill woven fabrics.

Rief *et al.* [15] created a virtual 3D multi-filament woven fabric using more than 100 2D microtome images of yarn sections. The software tool GeoDict®, specially developed at Fraunhofer ITWM, was needed to reconstruct the individual microtome images digitally in their accurate positions.

Jiraskova and Mouckova [16] expressed the non-periodical surface irregularity (unevenness) of flat textiles by means of the variation coefficient of greyness degrees of the woven fabric image in the grey scale. In order to evaluate woven fabrics, they divided the flat textile image into squared fields and calculated quantitatively the fluctuation of the colour shade (greyness degrees) among individual squared fields by means of the area-variation curve.

Optical coherence tomography (OCT) (Thorlabs, Callisto, Germany) makes use of photons in order to obtain images in a non-contact and non-destructive manner and has proven to be useful in taking sensitive measurements in many different areas. Especially in automated inspection systems are non-contact and non-destructive measurements crucial. Recently the OCT imaging setup was utilised in such an inspection system to precisely and automatically measure distances and infer gap widths with micrometer resolution [17] and then implemented in an automated quality monitoring scheme [18]. OCT imaging modality has also been applied in the field of textiles in order to, for example, examine the internal and (near-) surface structure of different types of polymers and composites subjected to different treatments and effects (Dunkers *et al.* [19], Dunkers *et al.* [20], Dunkers *et al.* [21], Wiesauer *et al.* [22], Stifter *et al.* [23], Awaja *et al.*[24]).

In a very recent study, Sabuncu and Özdemir [25] used OCT to identify the weave patterns of uni-coloured woven fabrics. To date, recognition of the weave pattern of striped fabrics has not yet been performed by image processing methods, because of the difficulties involved in the analysis. In this study we utilised the photonic imaging modality of optical coherence tomography (OCT) in order to automatically determine the weave patterns of striped woven fabrics non-destructively and non-contactly. We scanned an invisible infrared light centred at 930 nm over striped patterned plain and twill woven fabrics in order to infer their weave patterns .

Experimental

In this study, weave patterns of three different striped patterned woven fabric samples, whose weaves were plain and 2/1 twill, were measured using optical coherence tomography. While plain and 2/1 twill weave patterns are given in ***Figure 1,*** images of striped patterned woven fabric samples are shown in ***Figure 2.***

Optical coherence tomography of woven fabrics

In ***Figure 3*** we give the experimental set-up for the optical coherence tomography imaging of woven fabrics. A broadband diode centred at 930 nm with a 100 nm bandwidth generates the photons. The light waves reflected off the sample and reference arms interfere with each other in the fibre coupler. An optical grating divides the interference beam into separate spectral components. A Charge Coupled Device (CCD) then records each spectral component of the interference signal. We inserted the striped patterned fabric to be measured in the reference/sample arm. Invisible infrared optical waves produced by the super luminescent diode are projected onto the fabric surface, shown in ***Figure 2***. An infrared beam is scanned over the surface, creating an OCT signal. By applying a Fourier Transform to the signal measured, an A-scan image of the sample is generated. A-scan images created along a transverse plane of the fabric are combined sequentially to generate B-scan images. The reader can find more on OCT theory in the referred article [26]. The OCT imaging system had the following technical specifications: the light source had a central wavelength of 930 nm, the bandwidth of the light source was around 100 nm. The A-scan line rate and B-scan frame rate were 1.2 kHz and 512 lines/frame, respectively. The resolution in depth was 7 µm, whereas the lateral resolution was 8 µm. The Signal-to-Noise Ratio (SNR) of the measurement was around 80 dB. The average imaging depth was 1.7 mm.

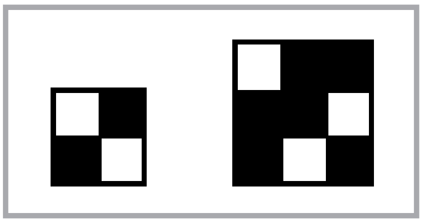


Figure 1. *Plain and 2/1 twill patterns used in the experimental study.*

The OCT measurement procedure

The fabric whose weave pattern is to be recognised is placed on a micro meter table in the sample arm as shown in ***Figure 3***. The light beam coming from the OCT Broadband diode is focused on the fabric. The length of the reference arm is adjusted by checking the signal reflected off the fabric-air interface. The adjustment is concluded when

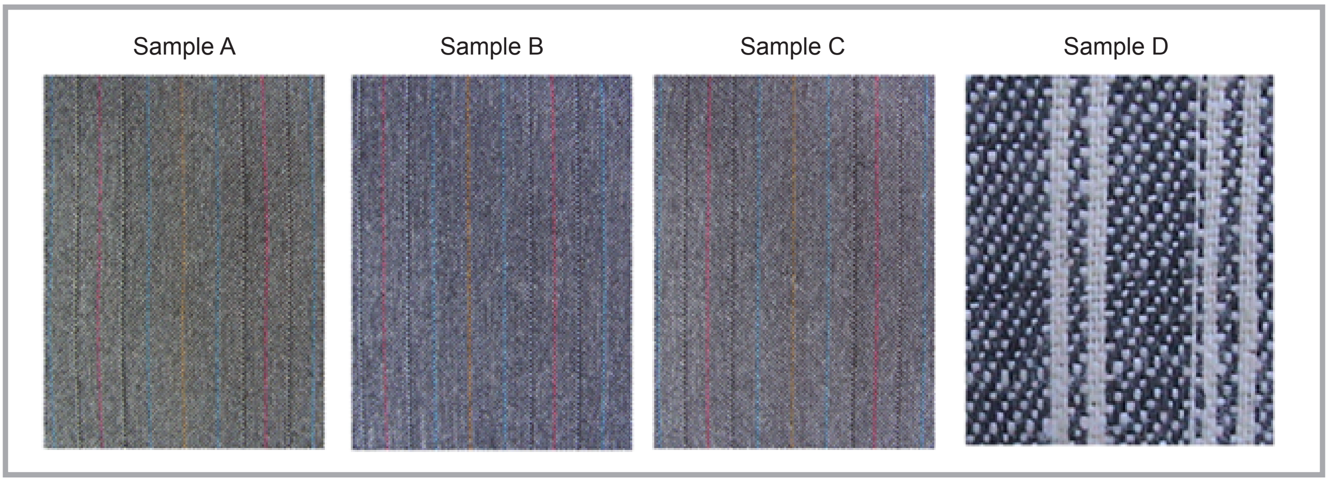


Figure 2. *Images of striped patterned woven fabric samples.*

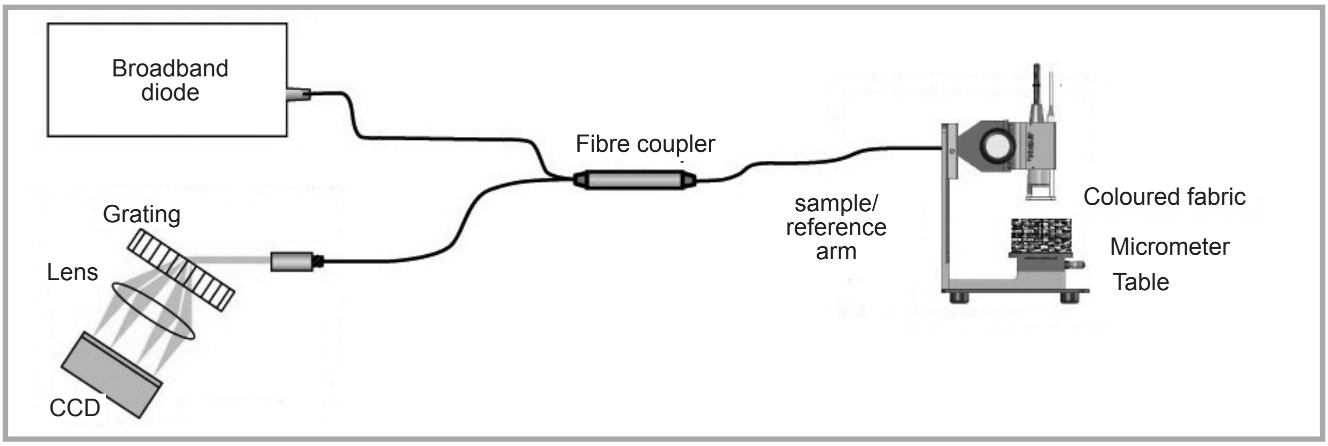


Figure 3. *Experimental setup.*

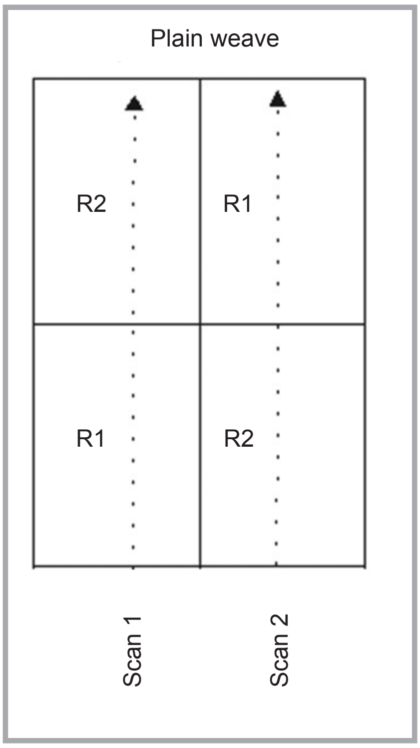


Figure 4. *Measurement procedure: OCT scans necessary for plain weave pattern. R1 & R2 denote reflections that correspond to surfaces 1 and 2, respectively.*

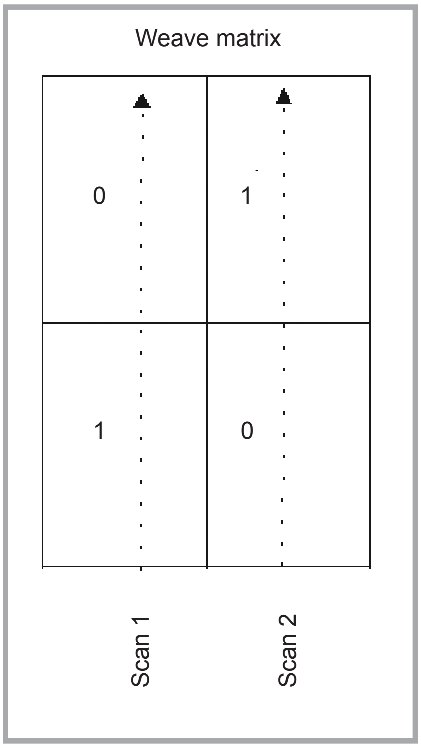


Figure 6. *The weave matrix was generated from two successive OCT scans corresponding to plain weave.*

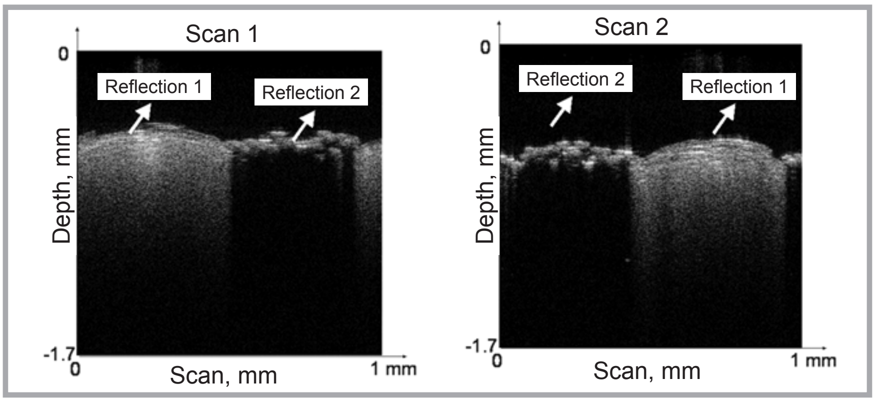


Figure 5. *OCT images taken from scans 1 & 2 over the fabric. The OCT scan reveals the different reflection characteristics of the surface. Reflections 1 and 2 correspond to R1 & R2 in* ***Figure 4.***

a sharp image is seen on the CCD camera. Fine-tuning is completed by optimising the OCT spectrum on the B-scan. The OCT imaging system is now ready to measure the fabric, which is placed in the reference arm such that the light beam first hits it from the top. The infrared beam then scans over the warp and weft regions of the fabric along the warp direction sequentially. The infrared beam was moved perpendicularly by a distance equal to the yarn diameter in order to extract the weave pattern of the striped fabric. The scanning process is performed again until similar cross sectional images of fabrics are taken, as shown in ***Figure 4***, in which R1 and R2 represent warp and weft yarns, respectively. Since the patterns obtained by scanning are related to the weave pattern, they will be periodical. For the plain weave pattern, the periodicity will be two. The reflection characteristic of the beam will depend on the region it is reflected off. The warp and weft regions will have their own unique reflection and, hence, OCT scan characteristic. Taking two successive OCT scans is quite enough for a fabric that has a plain weave pattern.

Results and discussions

In ***Figure 5,*** OCT images corresponding to two successive scans of a sample are given. As the infrared beam propagates in air whilst approaching the fabric, the beam does not see any reflections, since this region is black. When the light beam sees the fabric, due to the abrupt reflection index change, there are reflections, which are seen as white portions in the scan. One can easily notice two different reflecting surfaces, denoted by Reflection 1 & 2 in the scans. The warp and weft regions of the fabric

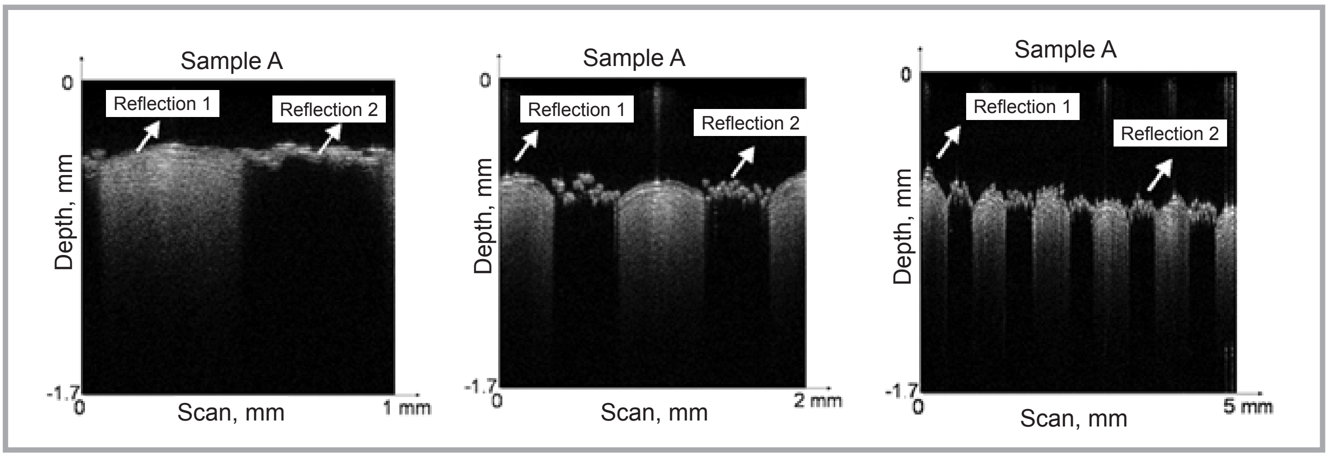


Figure 7. *OCT scans of fabric A with varying scan length (1, 2 and 5 mm).*

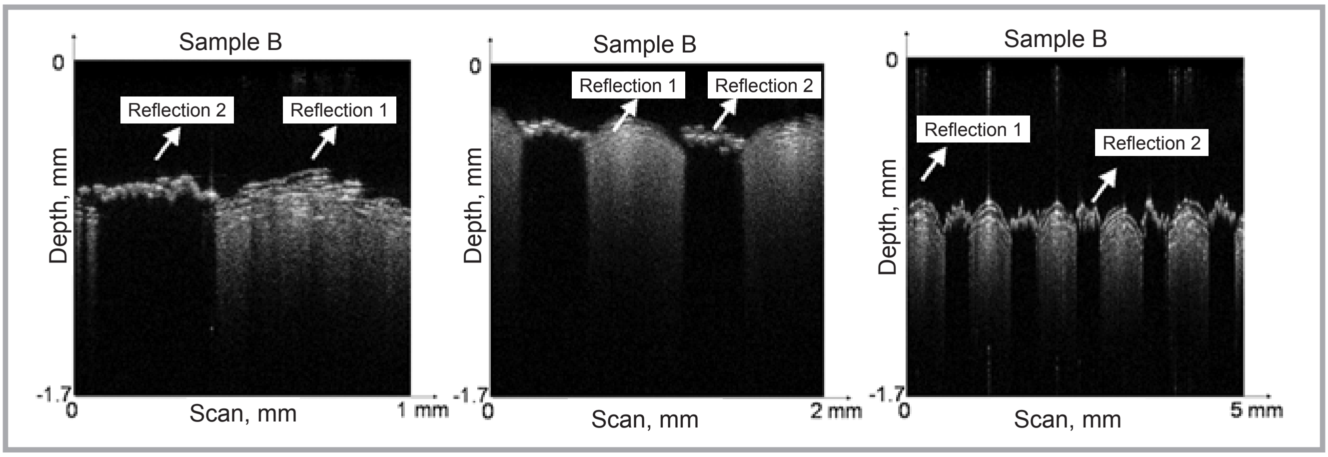


Figure 8. *OCT scans of fabric B with varying scan length (1, 2 and 5 mm).*

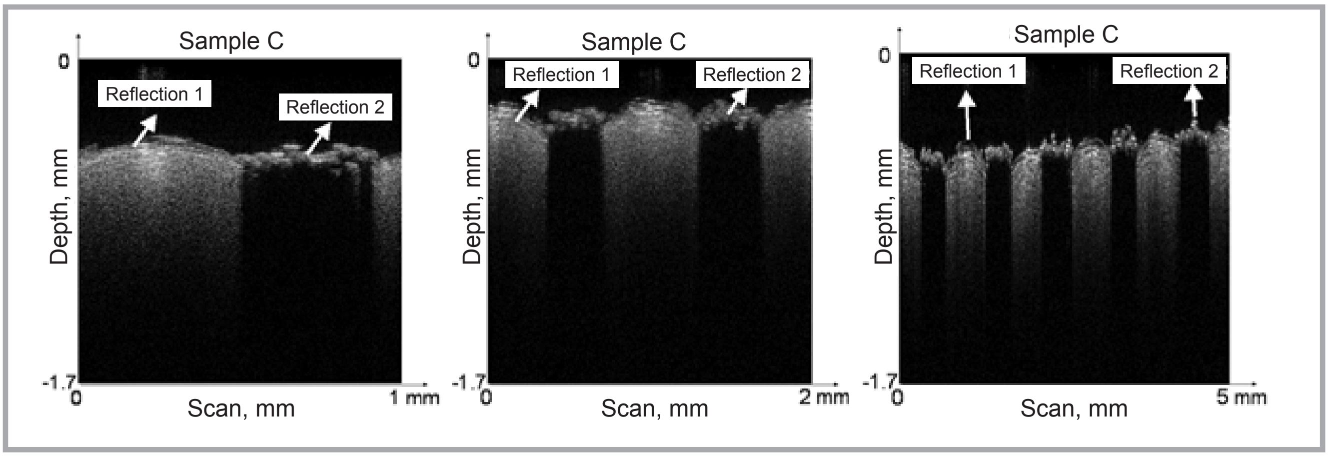
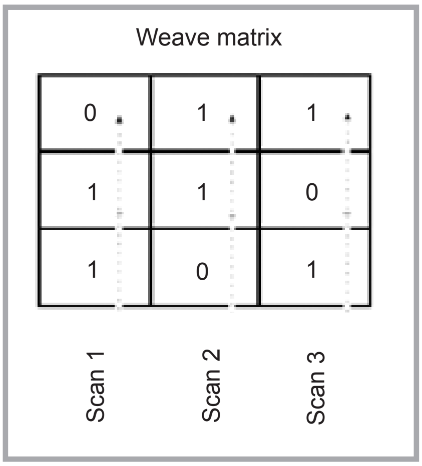


Figure 9. *OCT scans of fabric C with varying scan length (1, 2 and 5 mm).*

have two distinct reflection characteristics. It was seen that reflection 1 occurs from the warp surface and reflection 2 from the weft surface. Since the laser beam travels from air towards the fabric, we mark a region as Reflection 1 where the warp is above the weft. Similarly a region is marked with Reflection 2 if the warp yarn is below the weft. Hence this scan gives us the profile of the weave. Therefore by looking at the OCT scan, reflection 1 corresponds to the section where the warp passes over the weft, and reflection 2 to that where the warp passes under the weft. In the matrix, a "1" denotes that the warp is over the weft and a "0" that the weft is over the warp [27]. Moreover the periodicity of the pattern can be inferred from this particular scan. The OCT scan reveals that the periodicity of this pattern is two, which means that recognition of the weave structure will require two successive image scans. From this scan the weave matrix is inferred, given in ***Figure 6***.

It is important to note that the OCT scan measures differences in the refractive index and is therefore colour independent. Thus it is useful and feasible to ap-



0	1	1
1	1	0
1	0	1

__Figure 10.__ Weave matrix generated from three successive OCT scans corresponding to a 2/1 twill weave.

ply OCT to striped patterned fabrics, since the OCT scan sees the texture, not the colour. As the scan length of the beam was increased, the structure of the scans remained the same for all fabrics (***Figure 7, 8*** & ***9***). We also give OCT scan results that correspond to different scan lengths. An OCT scan was also taken by shifting the fabric orthogonal to the laser beam scan direction by an amount equal to the yarn diameter, shown in ***Figure 5.*** The OCT images show that the fabric is plain woven.

The same procedure was implemented for all of the samples (fabrics A, B and C). From the OCT scans given in ***Figure 7, 8,*** and ***9,*** it can be clearly seen that all the fabrics have a weave structure which is symmetric and has a periodicity of two. From the OCT scans given in the figures, we conclude that all the samples (A, B and C) are plain woven fabrics.

Using the same method as for fabric A, we determined that the weave matrix for fabrics B and D is the same as for fabric A, as shown in ***Figure 6.*** This matrix corresponds to a fabric of plain weave structure; thus we concluded that the samples are plain woven fabric also.

Fabric D was also scanned with OCT. The scans revealed that the fabric had a 2/1 twill weave pattern with a periodicity of three. The weave matrix of the fabric is determined from the scans and given by the matrix, shown in ***Figure 10.*** Therefore three successive scans, as shown in ***Figure 11***, were required for identification of the weave pattern.

Therefore we can conclude that OCT photonic imaging modality is a noncontact and non-destructive imaging tool that is able to recognise the weave patterns of the striped patterned woven fabrics with 100% accuracy. The weave pattern is inferred by generating a weave matrix from the OCT. Thus the resolution of the OCT determines the capability and success rate of the procedure. Our method will be successful when applied to fabrics that have yarns with a diameter larger than 10 µm, since our OCT scan had a resolution around 10 µm. The OCT method will fail for textiles that have yarns that are less than 10 µm in diameter, since details of the pattern will not be able to be resolved. Since OCT is colour independent, we conclude that the method is feasible for pattern detection on textiles that are striped patterned.

Conclusions

In order to determine a weave pattern manually, individual warp or weft yarns are extracted from the fabric. This procedure can be slow and is prone to error due to its manual nature. Therefore it makes sense to use automatic methods instead in order to determine the fabric weave pattern [28 - 30]. But these methods, in general, require complex image processing algorithms and are successful when applied to plain fabrics that are not striped patterned. In this study, we utilised optical coherence tomography scan images to recognise the plain and 2/1 twill weave pattern of commonly used striped woven fabrics automatically.

Optical coherence tomography scans were used to non-destructively extract the repeat of weaves via non-contact measurements. Thanks to the colour independence and high resolution of the method, the success rate was 100%, which proves that optical tomography can be used for the recognition of weave patterns of striped fabrics. This technique can be adopted in automatic inspection systems in the textile industry.

Acknowledgment

M.S. acknowledges a research grant (Grant No: BAP 20119) provided by Dokuz Eylul University.

References

1. Başer G. *Factors affecting quality in weaving and weaving process control techniques applied.* Lecture Notes. İzmir: Dokuz Eylül University, Department of Textile Engineering; 2007.
2. Xu ZK, Deng ZM, Zhao Y and Chen, LT. Research actuality on automatic measure method of fabric density. *Progress in Textile Science and Technology* 2005; (6): 3-5.
3. Zhang J, Xin B, Wu X. A review of fabric identification based on image analysis technology. *Textiles and Light Industrial Science and Technology* 2013; (3): 120-130.

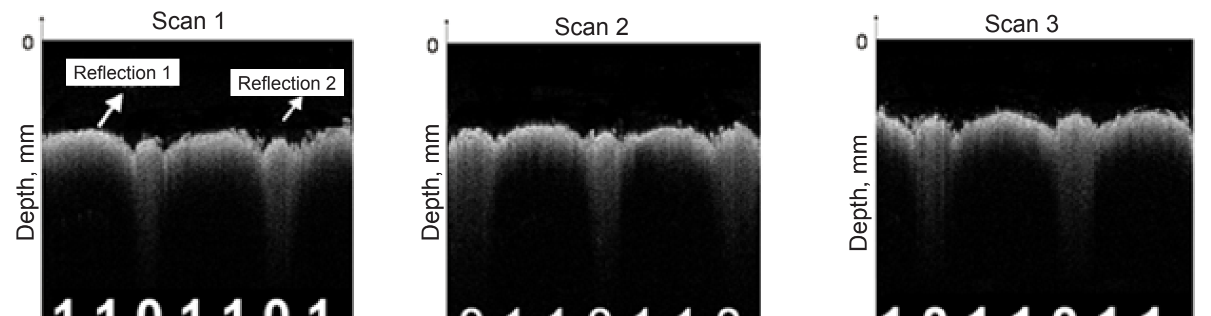


__Figure 11.__ Three successive OCT scans of fabric D.

4. Lachkar A, Gadi T, Benslimane R, D'Orazio L, Martuscelli E. Textile woven-fabric recognition by using fourier image-analysis techniques: Part I: a fully automatic approach for crossed-points detection. *The Journal of the Textile Institute* 2003; (3-4): 194-201.
5. Lachkar A, Benslimane R, D'Orazio L, Martuscelli E. Textile woven fabric recognition using Fourier image analysis techniques: Part II – Texture analysis for crossed-states detection. *The Journal of the Textile Institute* 2005; (3): 179-183.
6. Shady E, Qashqary K, Hassan M, Militky J, Image Processing Based Method Evaluating Fabric Structure Characteristics. *FIBRES & TEXTILES in Eastern Europe* 2012; 20, 6A(95): 86-90.
7. Liqing L, Jia T, Chen X. Automatic recognition of fabric structures based on digital image decomposition. *Indian Journal of Fiber & Textile Research* 2008; 33: 388-391.
8. Ajallouian F, Tavanai H, Palhang M, Hosseini SA, Sadri S, Matin K. A novel method for the identification of weave repeat through image processing. *The Journal of the Textile Institute* 2009; (3): 195-206.
9. Pan R, Gao W, Liu J, Wang H. Automatic recognition of woven fabric pattern based on image processing and BP neural network. *The Journal of the Textile Institute* 2011; (1): 19-30.
10. Salem YB, Nasri S. Automatic recognition of woven fabrics based on texture and using SVM. *Signal, Image and Video Processing* 2010; (4): 429-434.
11. Shen J, Zou X, Xu F, Xian Z. Intelligent recognition of fabric weave patterns using texture orientation features. In: *Communications in Computer and Information Science* 2010; 106: *Proceedings of Information Computing and Applications International Conference Part II* (ed. R Zhu, Y Zhang, B Liu, C Liu); 2010 Oct 15-18; Tangshan, China. Berlin: Springer; 2010. p. 8-15.
12. Potiyaraj P, Subhakalin C, Sawangharsub B, Udomkichdecha W. Recognition and re-visualization of woven fabric structures. *International Journal of Clothing Science and Technology* 2010; (2-3): 79-87.
13. Xiao Z, Nie X, Zhang F, Geng L. Recognition for woven fabric pattern based on gradient histogram. *The Journal of the Textile Institute* 2014; (7): 744-752.
14. Zheng D. A new method for the detection and classification of weave pattern repeat. *Textile Research Journal* 2014; (15): 1586-1599.
15. Rief S, Glatt E, Laourine E, Aibibu D, Cherif C, Wiegmann A. Modeling and cfd-simulation of woven textiles to determine permeability and retention properties. *AUTEX Research Journal* 2011; (3): 78-83.
16. Jiraskova P, Mouckova E. New method for the evaluation of woven fabric unevenness. *AUTEX Research Journal* 2010; (2): 49-54.
17. Sabuncu M, Akdoğan M. Utilizing Optical Coherence Tomography in the Nondestructive and Noncontact Measurement of Egg Shell Thickness. *The Scientific World Journal* 2014; (51): 91-95.
18. Sabuncu M, Akdoğan M. Photonic Imaging with Optical Coherence Tomography for Quality Monitoring in the Poultry Industry: a Preliminary Study. *Revista Brasileira de Ciência Avícola* 2015; (3): 319-324.
19. Dunkers JP, Parnasa RS, Zimbaa CG, Petersona RC, Flynna KM, Fujimotob JG, Bouma BE. Optical coherence tomography of glass reinforced polymer composites. *Composites: Part A* 1999; 30: 139-145.
20. Dunkers JP, Phelan FR, Sanders DP, Everett MJ, Green WH, Hunston DL, Parnas RS. The application of optical coherence tomography to problems in polymer matrix composites. *Optics and Lasers in Engineering* 2001; 35: 135-147.
21. Dunkers JP, Sanders DP, Hunston DL, Everett MJ, Green WH. Comparison of optical coherence tomography, x-ray computed tomography, and confocal microscopy results from an impact damaged epoxy/e-glass composite. *The Journal of Adhesion* 2002; (2): 129-154.
22. Wiesauer K, Pircher M, Götzinger E, Hitzenberger CK, Oster R, Stifter D. Investigation of glass-fibre reinforced polymers by polarisation-sensitive, ultra-high resolution optical coherence tomography: Internal structures, defects and stress. *Composites Science and Technology* 2007; 67: 3051-3058.
23. Stifter D, Wiesauer K, Wurm M, Schlotthauer E, Kastner J, Pircher M, Götzinger E, Hitzenberger CK. Investigation of polymer and polymer/fibre composite materials with optical coherence tomography. *Measurement Science and Technology* 2008; 19: 1-8.
24. Awaja F, Arhatari B, Wiesauer K, Leiss E, Stifter D. An investigation of the accelerated thermal degradation of different epoxy resin composites using X-ray microcomputed tomography and optical coherence tomography. *Polymer Degradation and Stability* 2009; 94: 1814-1824.
25. Sabuncu M, Özdemir H. Recognition of Fabric Weave Patterns Using Optical Coherence Tomography. *The Journal of the Textile Institute* 2016; (11): 1406-1411.
26. Schmitt JM. Optical coherence tomography (OCT): a review. Selected Topics in Quantum Electronics. *IEEE Journal of Selected Topics in Quantum Electronics* 1999; (4): 1205-1215.
27. Sabuncu M, Özdemir H, Akdogan M. Automatic Identification of Weave Patterns of Checked and Colored Fabrics Using Optical Coherence Tomography. *IEEE Photonics Journal* 2017; (5): 6900708.
28. Polipowski M, Więcek P, Więcek B, Jasińska I. Study on Woven Fabric Structure Using 3D Computer Image Analysis for In-Depth Identification of Thread Channels. *FIBRES & TEXTILES in Eastern Europe* 2015; 23, 2(110): 33-39.
29. Pan R, Zhang J, Li Z, Gao W, Xu B, Li W. Applying Image Analysis for Automatic Density Measurement of High-tightness Woven Fabrics. *FIBRES & TEXTILES in Eastern Europe* 2016; 24, 2(116): 66-72. DOI: 10.5604/12303666.1191429
30. Ezazshahabi N, Tehran MA, Latifi M, Madanipour K. Surface Roughness Assessment of Woven Fabrics Using Fringe Projection Moiré Techniques. *FIBRES & TEXTILES in Eastern Europe* 2015; 23, 3(111): 76-84. DOI: 10.5604/12303666.1152508

Received 21.01.2016 ***Reviewed 30.11.2017***