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Application of image analysis method for measurement of fabric stretch deformation

N Jariyapunya¹ and S Baheti²
¹Technical University of Liberec, Faculty of Textile Engineering, Department of Clothing, Studentská 2, 461 17 Liberec, Czech Republic
²Technical University of Liberec, Faculty of Textile Engineering, Department of Textile Evaluation, Studentská 2, 461 17 Liberec, Czech Republic

Email: nareerut.j@en.rmutt.ac.th

Abstract. For design of comfortable knitted fabric garments, it is necessary to know their distribution of elastic properties under the deformation. The standard tensile testing methods are not sufficient to explain distribution of these stretch properties. However, digital image analysis technique adjusted to the standard tensile test method can perform detailed study on distribution of local elastic deformation properties. The aim of this research was to develop a new method for the measurement of the local deformations between dots of stretch knitted fabrics during tensile testing. The image analysis approach was selected to calculate the gradient deformation tensor under the extension ranging from 10%, 20%, 30% and 40% in respective course, wale and bias directions. Moreover, this method was applied to know the deformation distribution on cylindrical surface as well by stretching the fabric under different extension. Subsequently the analysis of the deformation distribution by image processing system in MATLAB was carried out to determine the compression between cylindrical model and specimens. The results of image analysis were compared with ASTM D4964-96 standard and the actual obtained experimental results.

1. Introduction

Stretch fabrics are considered to be of high importance in order to produce comfortable tight-fitting garments with suitable pressure comfort [1, 2]. The clothing pressure exerted by tight-fitting is a kind of force that occurs on the surfaces between clothing and human body. It is due to change in extension and deformation of stretch fabric during contact with the body. For higher extension, there is higher deformation of stretch fabric which results in higher pressure. Therefore, the deformation characteristics are very important for stretch clothing from the comfort aspects [3]. The measurement of deformations has always been an important topic in the evaluation of material properties, such as material strengths or fracture parameters. However, a current problem in the characterization of fabric stretch deformation is the difficulty of its measurement by manual methods such as tape measure, ruler, vernier caliper, etc.

The digital image analysis is a state of art technique that can be used for accurate stretch measurement. By using the universal tensile test supplemented with an image analysis system, it is possible to capture not only the overall fabric deformation, but also the formation of localized deformation zones. Image analysis is well suited for the characterization of material properties due to faster data acquisition. It also has advantages of full field, non-contact, and high accuracy for
displacement and strain measurements [4]. However, the drawback of this method is its sensitivity towards the surface of the research object. In addition, the digital camera characteristics, camera place and direction toward the object, the distance between the object and camera, and illumination conditions are important parameters to avoid the occurrence of image analysis errors [5,6].

The aim of this work was to use image analysis technique for measurement of fabric stretch deformation and further investigation on local textile deformations during the tensile testing of knitted fabrics as per ASTM D4964-96 standard in course, wale and bias directions. Moreover, this method was further applied to know the deformation distribution on cylindrical surface by stretching the fabric under different extension.

2. Materials and methods

2.1. Materials

The stretch interlock knitted fabric containing 80 % Polyamide (PA) and 20 % Lycra, having aerial density of 197.59 g/m² and thickness of 0.57 mm was selected for the experiment. The fabric was conditioned for 24 hours before actual testing in standard atmosphere of 21 ± 1°C temperature and 65 ± 2% relative humidity. For the image acquisition and analysis, the specimen was applied with dot pattern of black color and the distance between the dots kept at 1 cm both in X axis and Y axis all over the fabric surface in wale (sample 1), course (sample 2) and bias (sample 3) direction.

2.2. Methods

2.2.1. Concept of gradient deformation tensor

The concepts of gradient deformation tensor are introduced to quantify the change in shape of infinitesimal line elements in a solid body. Figure 1 shows the straight line drawn on the undeformed configuration of a solid. However, after the deformation, the line becomes as a smooth curve.

![Figure 1. Concept of gradient deformation tensor](image-url)

When we focus attention on a line segment \( dx \), much shorter than the radius of curvature of this curve, the segment would be straight in the undeformed configuration and almost straight in the deformed configuration. Thus, no matter how complex a deformation we impose on a solid, infinitesimal line segments are merely stretched and rotated by a deformation. If we know the displacement field in the solid, we can compute \( dy \) from the position vectors of its two end points [7].

\[
dy_i = x_i + dx_i + u_i(x_k + dx_k) - (x_i + u_i(x_k))
\]  

(1)

Expand \( u_i(x_k + dx_k) \) as a Taylor series

\[
u_i(x_k + dx_k) \approx u_i(x_k) + \frac{\partial u_i}{\partial x_k} dx_k
\]  

(2)

\[
dy_i = dx_i + \frac{\partial u_i}{\partial x_k} dx_k = (\delta_{i1} + \frac{\partial u_i}{\partial x_k}) dx_k
\]  

(3)

We identify the term in parentheses as the deformation gradient, so

\[
dy_i = F_{i1} dx_k
\]  

(4)

In general, deformation gradient tensor is given by

\[
F = I + \nabla \mathbf{u}
\]

or in Cartesian components
\[ F_{1i} = \delta_{1i} + \frac{\hat{e}u_i}{\hat{e}u_k} \]  
\[ F = \begin{pmatrix} 1 + u_1 \\ u_2 \\ 1 + u_2 \end{pmatrix} \]  

Where \( \nabla u \) is the displacement gradient tensor, also expressed as \( \frac{\hat{e}u_i}{\hat{e}u_k} \) and \( I \) is the identity tensor described by the Kroneckor delta symbol as

\[ \delta_{i1} = \begin{cases} 1, & i = k \\ 0, & i \neq k \end{cases} \]

2.2.2. Image processing with standard tensile method

The specimens were cut in wale, course and bias directions with dimensions of (length x width) of 30 cm x 5 cm. The digital image analysis was applied for the standard textile tension test ASTM D 4964–96. The tensile force was applied at a speed of 100 mm/min and the gauge length was fixed at 20 cm. For the image acquisition and analysis, the specimen was applied with dot pattern of black color and the distance between the dots kept at 1 cm both in X axis and Y axis all over the fabric surface. The images of stretched textile specimen were captured by a digital camera with resolution 4000 x 3000 pixels, ISO 200, aperture F 2.2, shutter speed 1/15s and distance to camera of 50 cm. The sequences of deformed images at every step of 10 % of specimen elongation are shown in Figure 2(a-d). A special algorithm was developed in MATLAB 7.10 (R 2010a) to automatically track the motions of the dots and compute their centroid coordinates in a sequence of images before and after particular extension percentage.

![Figure 2. Captured images under different extension percentage][3]

2.2.3. Image processing with cylindrical model method

The specimens were cut with dimensions of (length x width) of 89 cm x 10 cm in each direction and were applied with dot pattern of black colour as discussed in previous section of tensile test. The specimen was selected for analysis in wale, course and bias directions of fabric after covering on the cylindrical model diameters of 24 cm and circumference of 79 cm. The high quality size RGB images were captured with resolution 4000 x 3000 pixels, ISO 200, aperture F 2.2, shutter speed 1/15s and distance to camera of 50 cm. The sequences of deformed images at every step of 10 % of specimen elongation are shown in Figure 3(a-d).

![Figure 3. Captured images under different extension percentage at wale direction of cylinder model][3]
3. Results and discussions

The results of images generate by MATLAB image processing tool box, the values of specimen local displacements in the longitudinal and perpendicular to the tension directions were estimated calculating the variation of each grid point height and width at every step of specimen elongation. Figure 4 (a-f) shows the calculated values of gradient deformation tensor for 0 %, 10 %, 20 %, 30 % and 40 % extension in course direction of knitted fabrics by tensile tester. It was clear that the images got stretched along with the points marked on them under different extension. In the figure 4(b) shows the value no extension and the result of image processing.

\[
F = \begin{pmatrix}
1 + u_1 & u_1 \\
u_2 & 1 + u_2
\end{pmatrix}
= \begin{pmatrix} 1.000 & 0.000 \\ 0.000 & 1.000 \end{pmatrix}
\]

When the value of \((1 + u_1)\) is deformation gradient in X axis and \((1 + u_2)\) is deformation gradient in Y axis.

In the case Figure 4(c) at 10% extension represent deformation guardian according to dot pattern of black colour was applied on the fabric is 1.00 cm. Therefore, the fabric deformation gradient in X axis was changed from 1.00 cm to 0.978 cm and Y axis from 1.00 cm to 1.098 cm.

The application of the image analysis method was successfully to find out the deformation of stretch fabric and the results represented the value of fabric change under difference extension that used images from tensile tester (method 1) and cylindrical model (method 2) as shown in the Table1. Width is the perpendicular of fabric extension direction and length is the fabric extension direction. The method 1 exhibited the result of force value during capture of the images under difference extension by tensile tester according to ASTM D4964-96. The calculated gradient deformation tensor values were found to change in similar percentage as the level extension of fabric. Due to the fact that the fabric was extended by tensile tester its independence distribution deformation than the fabric covered on the surface of cylindrical model because the contact of two objects will have the friction between each other.
Table 1. The value of gradient deformation tensor in width and length

| Sample 1 | Sample 2 | Sample 3 |
|----------|----------|----------|
| 10%      | 20%      | 30%      | 40%      | 10%      | 20%      | 30%      | 40%      | 10%      | 20%      | 30%      | 40%      |
| Gradient deformation tensor in width |
| **Method 1** | 0.97 | 0.95 | 0.93 | 0.92 | 1.00 | 1.00 | 0.98 | 0.98 | 0.98 | 0.95 | 0.88 | 0.89 |
| Average | 0.010 | 0.008 | 0.008 | 0.009 | 0.010 | 0.014 | 0.008 | 0.013 | 0.015 | 0.011 | 0.026 | 0.007 |
| SD | 0.106 | 0.89 | 0.90 | 0.98 | 0.99 | 1.41 | 0.83 | 1.32 | 1.49 | 1.11 | 2.97 | 0.81 |
| **Method 2** | 0.96 | 0.96 | 0.93 | 0.87 | 0.98 | 0.97 | 0.94 | 0.93 | 0.99 | 0.95 | 0.89 | 0.83 |
| Average | 0.005 | 0.005 | 0.013 | 0.010 | 0.036 | 0.004 | 0.004 | 0.005 | 0.008 | 0.005 | 0.008 | 0.011 |
| SD | 0.055 | 0.56 | 1.41 | 1.20 | 3.20 | 0.45 | 0.44 | 0.55 | 0.85 | 0.50 | 0.89 | 1.32 |

Gradient deformation tensor in length

| Method 1 | 1.10 | 1.20 | 1.31 | 1.42 | 1.11 | 1.23 | 1.36 | 1.43 | 1.11 | 1.22 | 1.41 | 1.44 |
| Average | 0.011 | 0.015 | 0.018 | 0.019 | 0.017 | 0.014 | 0.019 | 0.023 | 0.021 | 0.036 | 0.020 | 0.013 |
| SD | 0.099 | 1.25 | 1.34 | 1.31 | 1.52 | 1.14 | 1.40 | 1.58 | 1.86 | 2.93 | 1.39 | 0.88 |
| **Method 2** | 1.20 | 1.20 | 1.37 | 1.65 | 1.09 | 1.22 | 1.42 | 1.58 | 1.10 | 1.25 | 1.44 | 1.60 |
| Average | 0.010 | 0.006 | 0.021 | 0.014 | 0.006 | 0.008 | 0.008 | 0.015 | 0.004 | 0.010 | 0.025 | 0.049 |
| SD | 0.082 | 0.51 | 1.57 | 0.83 | 0.59 | 0.69 | 0.53 | 0.95 | 0.32 | 0.78 | 1.74 | 3.09 |
| Force(N) | 1.31 | 2.48 | 3.61 | 4.59 | 0.30 | 0.58 | 0.91 | 1.22 | 0.52 | 0.98 | 1.48 | 1.95 |

Table 2. The result of pressure value of elastic fabric between fabric and cylindrical model

| Sample 1 | Sample 2 | Sample 3 |
|----------|----------|----------|
| 10%      | 20%      | 30%      | 40%      | 10%      | 20%      | 30%      | 40%      | 10%      | 20%      | 30%      | 40%      |
| Pressure value (mmHg.) |
| **Average** | 1.00 | 3.90 | 5.80 | 9.20 | 1.00 | 2.00 | 4.10 | 1.00 | 2.00 | 3.20 | 5.90 |
| SD | 0.00 | 0.32 | 0.42 | 0.42 | 0.00 | 0.00 | 0.00 | 0.32 | 0.00 | 0.00 | 0.42 | 0.32 |
| %CV | 0.00 | 8.11 | 7.27 | 4.58 | 0.00 | 0.00 | 0.00 | 7.71 | 0.00 | 0.00 | 13.18 | 5.36 |

The Table 2 presents the results of the compression between cylindrical model and specimens. The PicoPress was used as one of the acceptable testers for pressure measurement by many researchers [1,2,9,10]. For instance, Vinckx et al. used the tester to measure the interface pressure occurred from the compression of elastic garment on a cylinder [8]. The PicoPress probe which features circular air bag sensor. It has thickness of 0.2 mm when not inflated and of 3 mm when inflated. The probe diameter is 50 mm before the measurement. The probe is inflated with 2 cc of air by means of electronically controlled syringe integrated in the system. The experiment was set to measure each pressure point after trying-on the sample and was repeated five times after every 20 seconds.

![Figure 5. The relationships of force and extension](image-url)
The graph in the Figure 5 represents the force value and the percentage of elongation obtained from the tensile tester according to ASTM D4964-96. The average values of force were used to find its relationship with the percentage of elongation by simple linear regression. The sample 1 is wale direction of fabric extension and its coefficient of determination was 0.9984. Similarly, the $R^2$ of 0.9998 for sample 2 (course direction) and $R^2$ of 0.999 for sample 3 (bias direction) was obtained. It could be concluded that the relationship between the variables are very strong and simple linear regression model best fits the data.

4. Conclusions

The application of MATLAB image analysis method was performed for measurement of fabric stretch deformation by using the camera images captured during experiment. The image analysis algorithm of gradient deformation tensor was developed to automatically track the motions of the dots and compute their centroid coordinates in a sequence of images before and after particular extension percentage. The validation of obtained results with simulated images obtained from MATLAB image processing toolbox showed accurate implementation of gradient deformation tensor concept for determination of elastic distribution properties of knitted fabrics. The results represented successful implementation of image analysis method for measurement of fabric stretch deformation. In this way, the outcome of this study will help to develop pattern construction of clothing of stretch fabric with appropriate pressure distribution for comfortable body fitting.

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References

[1] N. Jariyapunya, J. Geršak, B. Musilová and S. Baheti 2016Designing and Patternmaking with Stretch Fabrics, Structure and Structural Mechanics of Textile Fabric, ISBN 978-80-7494-269-3, pp. 239-244.

[2] N. Jariyapunya, B. Musilová, J. Geršak, and S. Baheti 2016A Study of Mechanical Properties of Stretch Fabric and Pattern Construction to Evaluate Clothing Pressure, ISBN 978-80-7494-293-8, pp.62-67

[3] S. Baheti and N. Jariyapunya 2016Characterization of Knitted Fabric Tensile Deformation by Image Analysis, ISBN 978-80-7494-293-8, pp.32-38.

[4] Jang L, Smith L, Gothekar A, Chen X 2010Measure Strain Distribution Using Digital Image Correlation (DIC) for Tensile Tests pp 1–27.

[5] Sze Wei K, Saravanan K, Ridzuan Bin Abdul Latif M 2015Development of an optical strain measurement method using Digital Image Correlation.(Asian J Sci Res)

[6] Dargiene J, Domskiene J 2013Errors related to image analysis technique applied for the investigation of textile local deformations. (Fibers Polym) pp 74–80.

[7] Striz B. 2002MechanikaTextilii, Cast 1. ZakladyMechanikiKontinua [Scriptum] Liberec: Technical University of Liberec 2002, ISBN 80-7083-458-7.

[8] VINCKX L., BOECKX W. and BERGHMANS J 1990Analysis of the pressure perturbation due to the introduction of a measuring probe under an elastic garment, Medical and Biological Engineering and Computing, 28(2), pp. 133-138.

[9] G. Mosti, and S. Rossari 2008The importance of measuring sub bandage pressure and presentation of new measuring device, ActaVulnol, vol. 6, pp. 31-36.

[10] J. Al Khaburi, A.A. Dehghani-Sanjii, E.A. Nelson and J. Hutchinson 2011The use of PicoPress transducer to measure sub-bandage pressure, ICBEST International Conference on Biomedical Engineering Systems and Technologies.