Prediction of woven fabrics appearance based on yarn surface-area measurement system (YSMS)

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Abstract. To predict the fabric appearance quality from the yarn structure, a yarn surface-area measurement system is proposed. We characterize the fabric appearance quality based on its surface area (Coefficient of the variance of the fabric surface area (FSCV)) to evaluate the irregularity of the simulated fabrics. The simulated fabrics are processed by YSMS using an improved mathematical model in which the yarn with elliptical cross-section is flattened in the weaving process. Results confirm our method is viable and could help to quantify fabric appearance quality objectively. On the basis of our method, the fabric structure and appearance could be optimized and even controllable prepared with appropriate yarn.

1. Introduction

Predicting the surface appearance of woven fabrics from the yarn is substantial in achieving a low-cost evaluation of fabric quality in the textile industry. Some studies have been carried out in this perspective [1-3]. But from a commercial point of view, these presented works still have challenges in efficiently characterizing fabric texture. For example, the results of simulated fabric appearance is usually far away from real fabric appearance, additionally, in these presented studies, the yarn is always considered as a cylinder before weaving and even after weaving which is unrealistic[1, 4-5].

Some commercial measurements launched by Uster and Lawson-Hemphill simulated fabric from yarn irregularity values which were measured by capacitive or optical sensors. Jasper[5] predicted the knitted fabric structure from two kinds of yarn data sets: the one was the density of the yarn (measured by the capacitor sensors), and the other was yarn diameter (measured by optical sensors). Carvalho[6] developed a system for visualizing woven textiles based on image processing techniques, which was used for assessing quality of yarns and fabrics. Sub[7] simulated woven and knitted fabrics structure and evaluated the fabric quality by employing on-line yarn measurement system based on Constant Tension Transport(CTT). Also, Keefe[8] analyzed the basic plain weaves by considering the yarn as a closed curve swept along a center line path with an elliptical cross section. To arrive at a more accurate appearance, Özdemir and Baser[2,3] simulated fabric appearance based on both still yarn image and moving yarn image by considering yarn flattening in the fabrics. Most studies treated yarn as a cylinder before weaving, which was rather unsatisfactory based on a few findings. Researchers found out that the yarn cross-section tended to concentrate the structure into an irregular close-packed polygonal shape can be assumed as an elliptical shape[9-11]. In this study, we consider yarn with an elliptical cross-section before weaving and improve the model presented by Özdemir and Baser, and also predict the fabric image from the yarn image. In addition, we propose the coefficient of the variance of the fabric surface area (FSCV) to characterize the irregularity of the simulated fabrics.
2. Flattened yarn mathematical model

The cross section of the individual yarn and the yarn in fabric is assumed to be an ellipse. The perimeter of yarn cross section is presumed to be constant during weaving [12, 13].

In the Cartesian coordinate system, the ellipse equation is:

\[ x = a \cos(t), \ t \in [0,2\pi] \]
\[ y = b \sin(t), \ t \in [0,2\pi] \] (1)

The arc lengths \( S_e \) and \( S_e' \), shown in Figure 1, are given as:

\[ S_e = \int_{t_{i=1}}^{t_{i=n}} \sqrt{a^2 \sin^2(t) + b^2 \cos^2(t)} \, dt, \ i=1,2,\ldots,n \] (2)

\[ S_e' = \int_{t_{i=1}}^{t_{i=n}} \sqrt{a'^2 \sin^2(t) + b'^2 \cos^2(t)} \, dt, \ i=1,2,\ldots,n \] (3)

![Figure 1. Yarn elliptical cross-section (a) yarn before weaving, (b) yarn after weaving](image)

Where, \( a, b \) are the major and minor radius of the flattened yarn cross section before weaving; \( a' \) and \( b' \) are the major and minor radius of the flattened yarn cross section after weaving. The arc lengths \( S_e \) and \( S_e' \) are divided by \( \theta_i \) and \( \theta_i' \) respectively as shown in Figure 1. \( x_i, x_i' \) are the projection on the \( x \) axis, and \( t \) is the variable of integration.

As the arc length \( S_e' \) is equal to \( S_e' \) according to the assumption, the coordinate \( x_i' \) can be obtained. \( x_i' \) could be applied for resizing the images of yarn in the predicted fabric, and the yarn image resizing process is similar to the work of Özdemir and Baser[2].

3. Experiments

This study adopts yarn flattening principle during the weaving process. It is fundamental to collect more comprehensive yarn data sets. The yarn surface-area measurement system (YSMS) was set up to collect the images of yarn along two orthogonal directions. And then these yarn images were spliced together to generate a virtual fabric.

3.1. Yarn data collection

YSMS was designed to acquire the yarn images and calculate the perimeter of yarn cross section, which was identical to the yarn surface area per length. Dual Charge-Coupled Device (CCD) sensors were assembled along two orthogonal directions, which were demonstrated in Figure 2. And the perimeter could be calculated by the following equation:

\[ L = 4 \sqrt{\frac{d_1^2 + d_2^2 - \frac{\pi}{8f} \int_0^\pi \sqrt{1 - (1 - f^2) \sin(t)^2} \, dt} \] (5)

Where, \( d_1 \) and \( d_2 \) represent diameters respectively measured by CCD_1 and CCD_2, \( f \) is the yarn flattening ratio is a constant[11].

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3.2. Fabric Simulations

Captured yarn image shown in Figure 3 need to be mapped into actual fabrics to observe fabric unevenness. In figure 4 the woven structures are made from the yarn images captured by YSMS. In this study, woven fabric images were created as following steps:

i. Division of the yarn into two parts, one used for weft, another used for warp.

ii. Two parts of yarn were divided into weft yarns and warp yarns.

iii. Each weft and warp yarns was divided into weft and warp-units respectively.

iv. Every weft-unit and warp-unit was assembled to warp interlacing points, or weft interlacing points one by one by the method of weave differentiation with mathematical function [14] according to the desired weave structure.

The sequence of laid yarn images is vital when woven fabrics are mapped by the units. Because the sequence affects fabric unevenness and FSCV. The warp yarns and weft yarns are laid according to the sequence in Figure 5.
Figure 5. Sequence of yarn images were laid

Figure 6. Simulated fabric: (a) without proposed model, (b) with proposed model, (c) partial enlarged drawing of (a), (d) partial enlarged drawing of (b)

We achieved simulated fabric by adopting Fabric Simulating Software. The software was designed for visualizing the appearance of the desired fabrics, which was developed in C++ programming language and Visual Studio 2008 environment.
The obtained fabrics in Figure 6(a),(b) (4000 Pixels×4000Pixels) were composed of 100 weft yarns and 100 warp yarns (fabric width was W and length is L). In this paper, W, L could be approximated with the number of yarns when fabric cover factor is constant. Figure 6 (b) is the yarn in the fabric which is resized by the proposed yarn flattening mathematical model (equation (3),(4)). Figure 6 (d) is partial enlarged image of (b). In this picture, Some small holes are caused by yarn thin places, and some periodic fabric irregularities are resulted by yarn unevenness. This fabric unevenness may affect fabric appearance, strength, air and water penetration, absorption, reflectivity, dyeability, and fabric finishing.

4. Fabric unevenness characterization

To characterize the simulated fabric unevenness, the following method is used to characterize fabric unevenness with yarn surface-area (cross-section perimeter per length). The proposed method in equation (6) is similar to the variance-length found in spun yarns[16], which is based on the assumption that yarn surface area remained constant during the weaving process even though the yarn is flattened. The method was different from the previous work[1, 15] which characterized fabric unevenness by yarn mass or single direction diameter.

Similar to work carried by Günay, the simulated fabric \((W×L)\) is partitioned into several pieces with the same area\((m×n, m \text{ is width}, n \text{ is length of each pieces, could be approximated by the number of yarns in each segments})\) which is represented \(A_i\) \((i = 1...k, k = W/m)\). The Fabric Yarn-Surface \(CV(A_i)\) \((FSCV(A_i))\) is the coefficient of variation for varying unit yarn-surface-area versus the magnitudes of the unit yarn-surface-areas, equation (6).

\[
FSCV(A_i) = \frac{1}{P(A_i)\sqrt{\frac{1}{w_i l_i} \sum_w \sum_l [P_{r,c}(A_i) - [\bar{P}(A_i)]]}^2}
\]

\(FSCV(A_i)\) is yarn surface-area variance, \(w_i, l_i\) are the number of segments in length and width direction\((w_i = L/n, l_i = W/m)\). \(\bar{P}(A_i)\) is the mean value of the the sum of weft and warp yarn surface area for all unit. \(P_{r,c}(A_i)\) is the \(i^{th}\) value of the sum of weft and warp yarn surface area for the unit area \(A_i\) of at row \(r\) and column \(c\). For obtaining \(P_{r,c}(A_i)\), we collected all the surface area of weft-units and warp-units yarns which were identical to the perimeters of yarn cross-section per length. And the latter was calculated by YSMS.

\[
P_{r,c}(A_i) = P_{r,c,p} + P_{r,c,t} = \sum_{j=1}^{q_{r,c}} \sum_{l=1}^{L_d} L_t + \sum_{j=1}^{q_{r,c}} \sum_{l=1}^{L_d} L_t
\]

Where, \(P_{r,c,p}\) is the sum of warp units yarn perimeters in unit area \(A\) at row \(r\) and column \(c\), \(P_{r,c,t}\) is the sum of weft-units yarn perimeters in unit area \(A\) at row \(r\) and column \(c\). \(P_{r,c}\) is the number of warp-units, \(q_{r,c}\) is the number of weft-units, \(q_{r,c}\) is the number of warp yarn test point, \(q_{r,c}\) is the number of weft yarn test points determined by software. \(L_d\) is the perimeter test by FSMS.

5. Results

According to the mathematical model mentioned above, the influences of segment length and fabric size on the \(FSCV\) are studied. The results are exhibited in Figure 7. And other results calculated from Han’s method[17] are also demonstrated for comparison.

![Figure 7. The influence of FSCV and CB(A)curves: (a) m, (b) width of simulated plain fabrics](image-url)
In Figure 7(a), \( m = n = [1, 5, 10, 20, 25, 50] \) when \( i = [100, 20, 10, 5, 4, 2] \). The \( FSCV \) curve displayed in Figure 7(a) appears a violent decline and a following relative smooth drop. Because the increase of yarn number in the each separated area leads to the enlarge of the area and the subsequent attenuation of the difference of \( FSCV \). In Figure 7(b), the analysed \( FSCV \) of the five simulated fabrics consist of the same yarn images. The fabrics with different width (different in number of warp yarns): \( 100 \times 100 \) (No.1), \( 50 \times 200 \) (No.2), \( 25 \times 400 \) (No.3), \( 20 \times 500 \) (No.4), \( 10 \times 1000 \) (No.5). are applied for studying the influence of fabric size on \( FSCV \) when \( m = n = 10 \). The \( FSCV \) curve exhibited in Figure 7(b) displays a downward trend when the width of the fabric swell. This is attributed by comprehensive performance of yarn unevenness, yarn flattening and fabric structure. In Figure 7(a) and (b), the \( CB(A) \) curve is similar to the \( FSCV \), which confirms that our method is viable.

6. Conclusions
A novel woven fabric appearance prediction method is developed in this paper. A mathematical model is improved to resize the yarn images to fabric appearances, according to a ellipse cross-section of yarn assumption. A more precise evaluation coefficient called \( FSCV \) is developed to represent fabric unevenness on the basis yarn unevenness. And the influence of fabric size and segment length on the \( FSCV \) is analysed. The proposed method is available for predicting the fabric structure and appearance, which also provides an insight into optimization and even controlable preparation of fabric with appropriate yarn.

Acknowledgments
This work was supported by Chinese Universities Scientific Fund (CUSF-DH-D-2015014).

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