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Measurement of yarn density in woven fabrics using fringe projection moiré techniques

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Fringe projection Moiré, a novel, accurate and fast technique with high repeatability, has been developed in order to measure the yarn density in woven fabrics. In the experimental set-up, collimated laser beams illuminate a Ronchi grating to be projected on a fabric. In case the density of projected lines and fabric becomes the same, the desired moiré pattern is observed on the fabric. As a result, the measurement of the distance between grating and fabric can guide us to find out fabric yarn density by using simple equations. In this regard, twenty five groups of shirting woven fabrics consisting of five weave structures and five different weft densities have been tested. The results show that there is a high correlation (R^2 =0.9932) between the data obtained from the new and the conventional methods.

Keywords: Fringe projection**,** Moiré pattern, Woven fabric, Yarn density

Yarn density is one of the key parameters which influence the physical and mechanical properties of fabrics. Traditional methods of measuring woven fabric density are mainly based on manual operations.

Xu[1] took advantage of the parallel structures in the vertical and horizontal direction of a woven fabric, and used a Fourier image analysis technique to produce both the warp yarns and weft yarns image independently. These images were then used to compute warp density and weft density. Xu *et al.*[2] established a procedure for rapid and accurate measurement of yarn density. They used a computer generated grating to produce digital moiré interference on the fabric. The moiré image was then demodulated and processed with a phase-shifting technique, so that the moiré fringes could be extracted and counted. From the relation between the gratings and the moiré fringes, the yarn density was calculated. In another investigation by Kim *et al.*[3], a beta gauge system was designed and fabricated for fabric density measurement with high sensitivity. Pan *et al.*[4] presented a new method for automatic inspection of woven fabric density of coloured fabrics. In this method, the Hough transform was used to detect the skew angles of warp and weft yarns and then the pixel in the fabric image was projected along the skew direction. Warp and weft yarns can be segmented by locating the true minimum values. Then the density of the fabric can be calculated by counting the yarns in a unit length.

The aim of this investigation is to propose a novel, precise and high-speed method to measure yarn density, which only utilizes the set up information causing the formation of a specific fringe pattern on fabric.

Theoretical Consideration

The moiré is a similar effect of light and dark bands or fringes, produced by the superposition of two sets of grating lines when certain required circumstances are satisfied. Such grating lines might be physical transparencies or periodic variations of the reflectance of a surface, or they might be formed by interference between two light waves (projected on a surface). This technique can be applied for various applications, such as optical testing of aspheric surfaces, measurements of surface roughness, form measurement, measurements of deformation and strain, and the analysis of vibrations and flows[5-7]. A moiré pattern consists of light and dark fringe-like lines. It is obtained by producing a grating-like structure on the object by projecting either a grid or an interference pattern[8].

Structured light projection or fringe projection is a full-field optical method which is used to measure the microscopic three-dimensional object surface. The moiré topography method has become a common non-contact method for precise measurements of three-dimensional shapes. In the moiré topography method, a sinusoidal fringe structure light is projected onto the surface of an object and becomes a deformed

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fringe due to the height of the tested object[9]. A fringe pattern is generally projected onto an object surface and then viewed from another direction by a camera that acquires the image[10].

Experimental

Materials

In this study, 25 groups of shirting woven fabrics were used for measurement of their weft densities. These fabrics consisted of five different weave structures with five various weft densities. The detailed information of fabrics is gathered in Table 1. These fabrics were produced on an identical machine. All of them were comprised 100% polyester filament yarns for warp and 100% cotton yarns for weft. The warp yarn count was 100 denier and the weft yarn count was 30 Ne.

Testing Set up

First of all, samples with dimensions of 12 ×12 cm were prepared and stuck on black cardboard to prevent light passage through the fabric and positioned on a special pedestal.

Table 1- Fabric characteristics

Fabric code	Weave structure	Density, cm	
		Warp	Weft
F1	Plain	48	22.4
F2			25.6
F3			28.7
F4			32.0
F5			34.4
F6	Twill 3/1	48	22 0
F7			25.0
F8			28.4
F9			31.5
F10			33.6
F11	Twill 3/3	48	21.8
F12			25.0
F13			28.1
F14			31.3
F15			34.2
F16	Twill 2/2	48	22 0
F17			25.1
F18			29.0
F19			31.5
F20			33.3
F21	Twill 2/1	48	22.0
F22			25.7
F23			28.4
F24			31.7
F25			34.0

The set-up used for experiments is shown in Fig. 1. This set-up consists of a light source which in our case is a helium-neon laser beam. The helium-neon laser is a red beam at 632.8 nm with a cw (continuous wave form) output ranging from 1mW to 100 mW. It is the most widely used laser output wavelength. The laser should produce an intense, concentrated and highly parallel beam of coherent light, in order to obtain accurate results.

This laser beam passes through a mirror and then a spatial filter including focusing lens and a pin hole. The beams are paralleled and strengthened by passing through a collimating lens. The next part is a Ronchi grating with frequency of 5 lines/mm. The frequency of the grating is selected considering the fineness of the investigated surface. In case the surface becomes finer, the density of printed lines in a unit length should become more. For the range of fabrics used in this research, a grating with frequency of 5 lines/mm is suitable. The grating lines produced in this section are amplified by an achromatic lens (AC 508-250A) which is set as close as possible to the grating. In the next section, a pin hole is used for controlling the passage of the strongest light beam and its projection on sample (fabric). Finally, the projected lines and obtained pattern are captured by a digital camera (Canon EOS-350D). It should be noted that choosing the appropriate elements for the set-up and precise adjustment of its different components is crucial for achieving repeatable, correct and reliable data.The moiré pattern is formed by the superposition of projected Ronchi grating lines and the periodic structure of the fabric surface.

One of the requirements for producing the moiré effect between the two periodic patterns is that the frequencies of the grating pattern and fabric

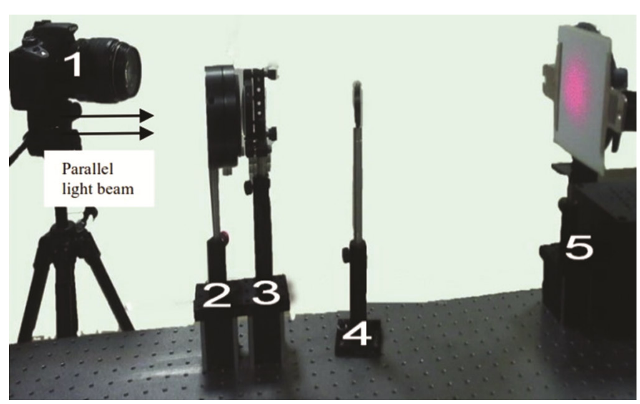

Fig. 1— Experimental set-up (1) camera, (2) Ronchi grating, (3) achromatic lens, (4) pin hole, and (5) fabric

(yarn density) must be the same. Thus, formation of a specific fringe pattern on the fabric surface can be a guide for measurement of yarn density. This specific pattern is visible in Fig.2.

In order to have similar frequencies for the grating pattern and fabric, the distance between Ronchi grating (5 lines/mm) and fabric should vary. By changing the distance between the Ronchi grating and fabric, the density of lines (number of projected grating lines on fabric in a unit length) which are projected on the fabric surface differs. In case the density of the projected grating lines and density of fabric become too close to each other in an identical direction, a small rotation of Ronchi grating (< 10°) can cause the desired moiré pattern, which is clear in Fig.2.

In this study, horizontal grating lines are projected on fabric, so it is possible to realize the fabric density in horizontal direction (in our case weft direction). It is interesting that the desired moiré fringe patterns occur in the vertical direction.

In order to have the density of projected grating lines on fabric, it is not necessary to count the lines in a unit length, which is so hard and time consuming. Since the distance between grating and fabric has a relationship with the number of grating lines projected on fabric, it is possible to calculate the number of grating lines by only measuring the distance between Ronchi grating and fabric. Having the number of grating lines projected on fabric is an indication of fabric density. The schematic of this set-up is shown in Fig.3.

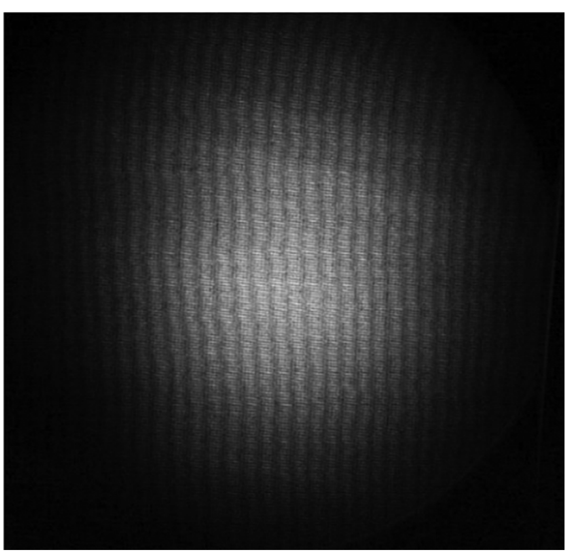

Fig.2 — Specific desired moiré pattern

As it is obvious from Fig.3, by varying the distance between grating and fabric, the value of L1+L2 changes, which leads to a change in number of grating lines projected on the fabric. The relationship between the measured distance and density of projected grating lines on fabric is not always linear due to some reasons such as light diffraction, edge effects, unevenness of lenses, etc. Thus, it is necessary to investigate and find the best function that can explain the correlation between distance and number of projected lines. The effort made in this regard is described in the subsequent section. It will be proven that this relationship follows a power function. Thus, measurement of the space between grating and fabric can guide us to find out fabric yarn density by using uncomplicated equations.

Results and Discussion

The first step to find out the relationship of the distance between grating and fabric and the density of projected grating lines (number of grating lines in a unit length) was the counting of the density of the projected lines in different distances. In this regard, the mentioned distance varied 21 times with 2.5 centimetre intervals. In each distance, the image of projected lines on fabric was recorded. Then via an image processing procedure by Matlab, which is described below, the number of projected lines in a unit length was measured.

First of all, it was necessary to prepare the captured image for precise measurement of the number of lines. In this regard, the contrast of image was adjusted to improve its quality and then by using a threshold function, the identification of various intensities over the image became better. In the next step, applying a morphological operation helped in making the lines thin for easier and more accurate counting. This function removes pixels, so that a line shrinks to a minimally connected narrow condition.

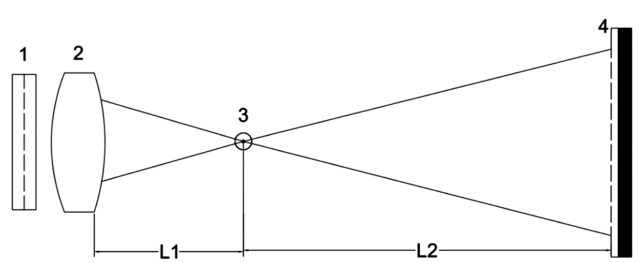

Fig. 3— Schematic of set-up (1) Ronchi grating lines, (2) achromatic lens, (3) pin hole, (4) projected grating lines, and (5) fabric

Finally, the number of lines was counted. The original and processed images are shown in Fig.4.

The results show that the relation between the distance of grating and fabric and the number of projected grating lines in a unit length follows a special trend. Focusing on the mentioned fact revealed that while the distance is smaller, the number of lines in a unit length is more. By increasing the distance between grating and fabric from 40 cm to 70 cm, the number of lines/cm reduces with a gradual slope. However, from 70 cm to 100 cm distance, the slope diminishes slightly. Thus, bearing in mind the tendency of data and also examining various functions to find the appropriate one for this case, it can be claimed that the power function has the ability to fit the data precisely and demonstrate their trend. The trend of this relation and the correlation factor for the suitability of this function can be seen in Fig.5.

Thus, by following Eq (1), it is possible to calculate the frequency of projected grating lines, at any distance of grating from the fabric:

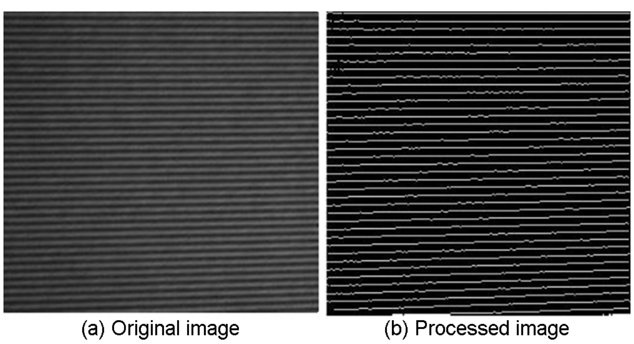

Fig.4— Image processing result

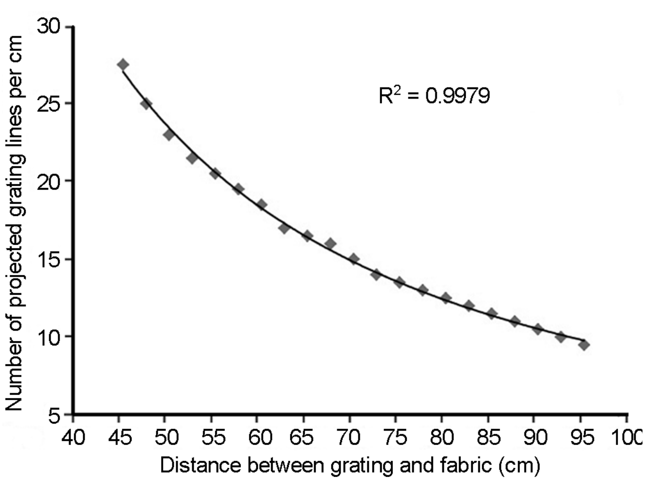

Fig.5 — Diagram of number of projected grating lines against distance between grating and fabric

$$Y = 5107.8X^{-1.373} \quad \ldots (1)$$

where y is the number of projected grating lines per cm; and x, the distance between Ronchi grating and fabric (cm).

As it has been mentioned before, the formation of the desired moiré pattern (Fig.2) is due to the fact that the frequency of projected grating lines and the density of fabric in an identical direction become too close (nearly the same). Thus, observation of this moiré pattern on fabric is an indication of similarity of these two frequencies.

For different types of fabric used for this investigation, in case of configuration of the moiré pattern, the distance between grating and fabric was recorded. These recorded data were fed to Eq (1). The results obtained from the equation are actually the density of projected grating lines; meanwhile showing the yarn density of the tested fabric. The results of calculations for all experimented fabrics are shown in Table 2. The values of weft densities, which were counted manually and by a magnifying glass, are also included in Table 2.

A comparison between the data achieved from the new method presented in this study and the manually counted densities show a good correlation (R^2=0.9932), which is the testimony for the efficiency

Table 2- Values of weft density

Fabric code	Counted weft density, cm	Distance of grating and fabric, cm	Calculated weft density, cm	Error %
F1	22.4	53.5	21.6	3.57
F2	25.6	47.5	25.5	0.39
F3	28.7	43.5	28.7	0.00
F4	32	40.5	31.7	0.94
F5	34.4	38.3	34.2	0.58
F6	22	53.5	21.9	0.45
F7	25	47.5	25.5	2.00
F8	28.4	43.5	28.7	1.06
F9	31.5	40.5	31.7	0.63
F10	33.6	39	33.4	0.60
F11	21.8	53.5	21.6	0.92
F12	25	47.5	25.5	2.00
F13	28.1	43.5	28.7	2.14
F14	31.3	41	31.2	0.32
F15	34.2	38.5	34.0	0.58
F16	22	53.5	21.6	1.82
F17	25.1	47.5	25.5	1.59
F18	29	43.5	28.7	1.03
F19	31.5	41	31.2	0.95
F20	33.3	39	33.4	0.30
F21	22	52.8	22	0.00
F22	25.7	47.5	25.5	0.78
F23	28.4	43.5	28.7	1.06
F24	31.7	40.6	31.6	0.32
F25	34	39.2	33.2	2.35

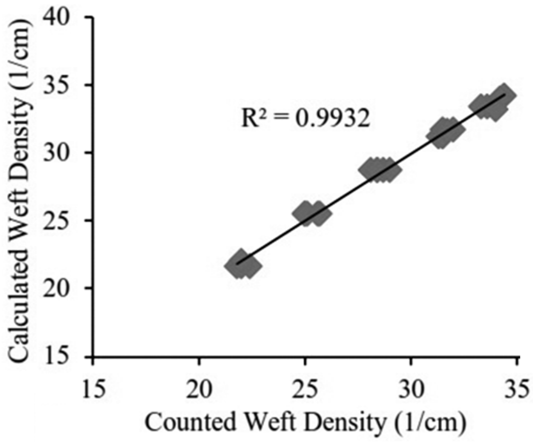

Fig.6 — Correlation between the data obtained from two methods

and accuracy of this method. In addition, the error percentages as shown in Table 2 can justify the suitability of the proposed method. The correlation between the data attained from both of the two methods is shown in Fig.6.

These results prove that it is possible to measure the density of woven fabrics which is one of the prominent properties of fabrics, by using a rapid, accurate and efficient method. In order to certify the repeatability and reproducibility of the new method, some tests were carried out and satisfactory results were obtained from these tests. Especially for determining this parameter for very dense fabrics where the counting of yarns is too difficult and time consuming, this method can be applied with a good precision. Besides the advantages of the new method which are mentioned above, it can be included that the proposed method is not sensitive to colour, weave structure and the type of material that the fabric is made of. Thus, this technique is applicable to various kinds of woven fabric with an appropriate accuracy.

Due to the importance of accurate determination of yarn density in woven fabrics, in the current work, a novel method for measurement of yarn density of woven fabrics is presented.

In this method, the formation of a specific moiré pattern caused by the interaction between fabric and grating is the guide for measurement of density. By making use of this technique, it is possible to measure a quantity on a large scale (scale of cm where the distance between grating and fabric is read) and report a quantity on a small scale (with precision of 0.01 mm, where the density of yarns in a fabric or the space between yarns in the fabric is calculated). This ability can improve the exactness of results to a great extent. In addition, the significant benefit of this method is that it is suitable for measuring the density of a wide range of woven fabrics, with different colours, material and structures.

This method is invented through the path for analysing the surface roughness of fabric by the moiré technique. The results of this part of the investigation will be announced in successive publications.

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