Optical method for the determination of the roughness profile of woven fabrics

S Vassiliadis¹, D Matsouka¹, 5, Q Watel² and H Jaouani³, 4

¹ Department of Electrical and Electronics Engineering, University of West Attica, Thivon 250, Egaleo, 122 44 Athens, Greece
² ENSAIT, 2 Allée Louise et Victor Champier, 59056 Roubaix, France
³ Higher School of Textile and Clothing Industry (ESITH), Route d’Eljadida, km 8, BP 7731 - Oulfa, Casablanca, Morocco
⁴ Department of Renewable Energy and Dynamics Systems, University Hassan II, Casablanca 20000, Morocco.
⁵ Author to whom any correspondence should be addressed

dmats@uniwa.gr

Abstract. Surface properties are important characteristics of textile fabrics. Apart from the tactile characteristics of the fabric, these properties can affect aspects of the fabric behaviour both in use and during further production processes. Fabric tactile characteristics and friction properties are just two of the properties connected to surface roughness. Typically surface roughness is determined using the KES-F system. This research paper proposes an innovative optical method for the measurement of fabric surface roughness based on image processing of photos of fabric cross-sections obtained through the stereoscopic microscope. Thirty parametric cotton woven fabrics were tested both in the warp and weft direction and the surface roughness for each fabric was obtained as a percentage of the void areas on the surface of the fabric.

1. Introduction
Fabric roughness is a property of fabrics connected with their surface properties. Roughness is a component of fabric “hand” and it affects surface friction properties, adhesion, and laminating and in more advanced applications, it could potentially influence properties such as flexible photovoltaic cell efficiency through light trapping [1]. While there exist a number of research papers that outline proposed methods for the determination of surface roughness, the only commercially available method currently in use is the Kawabata system (KES-F) [2-5]. The KES-F surface roughness method can determine the geometrical roughness and the coefficient of friction (µ) of the fabric. The measuring principle of the Kawabata system is based on the movement of a wire like probe over the surface of the fabric (Figure 1). The system translates the vertical movement of the sensor as it transverses the fabric surface into a proportional electric signal. Because of its design, the Kawabata system offers an averaged image of the surface roughness of the fabric. This is due to the relationship between the probe geometry and the usual range of numbers of yarns per unit length of woven fabric [2].
Figure 1. KES-F surface roughness probe.

Other methods for the determination of the surface roughness of woven fabrics as described in the relevant literature include the use of laser triangulation methods [4, 5]. These methods have not, as of the date of publication, resulted in the production of a commercially available device. Furthermore, the use of lasers for the determination of the surface roughness of fabrics has its own limitations, regarding things like the acceptable specimen colours (white or light coloured fabrics can be difficult to measure) and the need for a very precise alignment of the specimen in the measuring position, which could prove difficulty due to the flexible and elastic nature of textiles.

The method described in this research paper is based on measuring the actual fabric geometry without the need for expensive, specialized equipment. The 3D profile of the fabric surface is captured on photographs taken through a stereoscopic microscope. The photographs are then analysed using an image analysis software. Thirty fabrics were analysed, and their surface roughness was calculated as a percentage of the indentations between warp yarns that appear on the surface of the fabrics.

2. Materials and Methods

2.1. Materials

This paper presents the study of the influence of yarn density on the surface roughness of woven fabrics using image processing of fabric cross-section photographs obtained through a stereoscopic microscope. The surface roughness of thirty fabrics, in total, was investigated. The fabrics were 100% cotton, plain weave with linear densities of Nec 40 and Nec 50 for warp and weft respectively. Five yarn densities were used for the warp direction, from 54 to 66 yarns per cm, with a step of 3 yarns/cm. For each of these warp densities four samples were produced with a weft yarn density of 20 to 45 yarns per cm with a step of 5 yarns/cm (Table 1).

| i  | Warp yarn density (yarns/cm) | Weft yarn density (yarns/cm) | Mass/unit area (g/m²) |
|----|-----------------------------|------------------------------|----------------------|
| 1  | 54                          | 20                           | 101.0                |
| 2  | 54                          | 25                           | 110.3                |
| 3  | 54                          | 30                           | 119.5                |
| 4  | 54                          | 35                           | 127.3                |
| 5  | 54                          | 40                           | 136.7                |
| 6  | 54                          | 45                           | 144.1                |
| 7  | 57                          | 20                           | 101.2                |
| 8  | 57                          | 25                           | 111.1                |
2.2. Methods

Fabric cross-sections were obtained for all the samples and photographed under the stereoscopic microscope. An example of the cross-section of the specimens can be seen in Figure 2.

![Figure 2. Specimen cross section.](image)

The photographs were analysed using ImageJ image analysis software and the area that corresponded to the indentations created by the weft yarns was determined as a percentage of the total area of the photograph that corresponded to the fabric material. A visual representation of the definition of the void areas and the calculation of the corresponding area values can be seen in Figure 3. The photographs were cropped so that they only included the sample cross section and then the areas lacking material where outlined and the area was measured (i.e. the number of pixels was determined). The samples were analysed in both the warp and the weft directions.
3. Results – Discussion

The specimens examined under the stereoscopic microscope were prepared both in the warp and the weft directions. It should be noted that when the specimens were prepared along the warp direction, the weft yarns are prominent in the fabric cross section, while the warp yarns appear in a longitudinal form, while the reverse happens when the specimens are prepared in the weft direction.

The results obtained for the specimens prepared in the warp direction are presented in Figure 4 bellow. Figure 4 shows that the surface roughness of the specimens expressed as a percentage of the sum of the areas with no material (yarns) vs the total material in the specimen cross section is higher in the specimens with a lower warp density. Furthermore, when considering the same warp density, the surface roughness becomes lower with an increase in the weft yarn density.

![Figure 3. Measurement method.](image)

Figure 4. Surface roughness in warp direction specimens.

Figure 5 illustrates the results obtained for the specimens that were prepared in the weft direction. The Figure shows that the surface roughness of the specimens decreases as the warp density increases. Moreover, within the specimens with the same number of weft yarns per cm, surface roughness decreases as the weft yarn density increases.
Regarding the results in both directions, it is important to note that while the method can be thought to be only measuring the dimensions of the yarns that are visible through the cross section, the effect of the yarns in the perpendicular direction is evident. Specifically the tension applied to the visible yarns and the deformation caused due to the presence of the other yarns. Moreover, it is significant to note that the values for the surface roughness that are obtained when examining either direction (warp/weft) are not identical, which would is in step with the differences in fabric geometry in those directions. As materials fabrics are directional and quite similar to other products where the production direction has different properties than the direction that is perpendicular to the production direction e.g. paper.

4. Conclusions
The method outlined in this paper is presented as an alternative to the currently used methods that require expensive and specialized equipment. It is efficient as it provides actual measurement of the real geometry of the fabric and it can be applied to different fabric structures. The results obtained by using the method on a set of 30 fabrics to measure their roughness indicated a good agreement with what was described in theory of fabric structures.

References
[1] Lee S, Lee Y, Park J and Choi D 2014 Nano Energy 9 pp.88-93
[2] Akgun M, 2016 J. Text. I. 107 pp.1056-67
[3] Vassiliadis G S, Provatidis G C 2004 Int. J. Clothing Sc. Tech. 16 pp.445-57
[4] Mooneghi S A, Saharkhiz S, Varkiani S M H 2014 J. Engineered Fibers Fabrics 9 pp.1-18
[5] Ramgulam R B, Amirbayat J and Porat I 1993 J. Text. I. 84 pp.99-106.