AUTEX Research Journal, Vol. 14, No 1, March 2014, DOI: 10.2478/v10304-012-0046-0 © AUTEX

A PRINCIPAL COMPONENT ANALYSIS (PCA) METHOD FOR PREDICTING THE CORRELATION BETWEEN SOME FABRIC PARAMETERS AND THE DRAPE

Thouraya Hamdi[1], Adel Ghith[2], Faten Fayala[1]

[1]University of Monastir, National Engineering School, Thermal and Energetic Systems Studies Laboratory, Monastir 5019, Tunisia.
[2]University of Monastir, National Engineering School, Research Unit Automatic Image and Signal Processing, Monastir 5019, Tunisia.
E-mail: thourayahamdi@yahoo.fr, adel.ghith@enim.rnu.tn, fayala.faten@gmail.com

Abstract:

A new method for predicting correlation between fabric parameters and the drape is developed. This method utilises a Principal Component Analysis (PCA) of intercorrelated influencing parameters (bending rigidity, weight, thickness) and the drape parameters (drape coefficient and the node number). This paper describes the PCA procedure and presents the similarities and contrasts between variables.

Keywords:

Fabric drape, fabric parameters, bending rigidity, Principal Component Analysis (PCA)

Introduction

Drape is an important property showing how a fabric hangs under its own weight. When the fabric is draped, various configurations are found and different forms are obtained. This is due to the anisotropy of the structure of textile fabrics.

The study of the "drapability" of textile fabrics proved their capacities to become deformed and thus their aptitude to be harmonised with the bodies with which they are in contact. Non-conformity between the style of the draped model and the end use of garments must be avoided when choosing fabrics. This helps to get rid of several problems.

The drape coefficient provides an objective description of drape deformation in three dimensions. In several works, the study of three-dimensional drape in terms of drape coefficient is empirically related to two-dimensional drape in terms of bending properties. Cusick [6,7] proved by statistical evidence that fabric drape involves curvature in several directions and that the shear angle and bending length have an effect on the deformation. Mooraka and Niwa [9] studied the relation between drape coefficient and mechanical properties. They showed that bending rigidity and weight are the most critical parameters of drape. Chaudhary [3] conducted a study to predict drape coefficient by weaving parameters. He said that drape is strongly related to the weaving parameters. Jeong and Philips [13] found that fabric cover has a significant effect on fabric drape because of its effect on bending rigidity. The drape is influenced by crimp, fabric tightness and yarn interaction. Chen and Govindaraj [4] in their attempts observed that Young's modulus, shear modulus and thickness have varying effects on extent of fabric drape but Poisson's ratio has no significant effect on drape. Pant [14] found substantial increase in drape coefficient of acrylic and polyvinyl acetate-finished fabrics due to the increase in stiffness. However, with silicone finish, drape coefficient decreased slightly. Fathy [5] showed that the highest correlation has been found between the fabric drape and stiffness and the parameters which indicate fabric tightness. Agrawal [1] found that bending parameters are highly correlated to nodal parameters, and she proved that height of hanging is highly correlated to drape coefficient and nodal length [2].

Previous researchers have studied the relationship between some fabric parameters and the drape. It has been found that in most of the cases, their methods are time consuming.

In order to overcome this shortcoming, the present study proposes application of Principal Component Analysis (PCA) to prove the relationships between some structural properties of some fabrics and the drape parameters. PCA is used to transform a number of correlated variables into a number of uncorrelated ones. This sub-space method reduces the multidimensional data sets into lower dimensions for carrying the analysis. Thus, the main aim of this study is to extract certain conducting patterns from multidimensional data and to compare two groups of users: fabric parameters and drape parameters.

Materials and methods

Materials

Fifty-five woven fabrics with twill and plain weaves were chosen for preparation of the samples in this study. The fabric samples were conditioned in standard atmospheric conditions for at least 24 hours to allow them attain a stable condition before evaluating the drape. The fabrics are 80% cotton and 20% cotton/polyester.

The fabric weight was measured using French Standard NF G07-104. For the fabric thickness, the French Standard NF

G07-153 is used. The method of measuring the bending rigidity is presented below.

Measurement of bending rigidity:

The method used in this study to measure the bending (or flexural) rigidity B of fabrics is known as “Cantilever test” and is presented in Figure 1. It enables the measurement of the fabric bending rigidity in weft, warp and skew directions. The test method consists in clamping a horizontal strip of each fabric at one end and the rest of the strip is slipped and allowed to hang under its proper weight. When the tip of the strip reaches a plane inclined at 41.5° below the horizontal, the overhanging length is measured and noted (L).

The bending rigidity was calculated using the following equation [16]:

$$B_{(\mu N.m)} = W_{(\frac{g}{m^2})} C^3_{(cm^3)} 10^{-2} \quad (1)$$

where: C = L/2 and L is the bending length in cm, W the fabric surface mass in g/m^2, B the bending rigidity in μN.m.

The above formula was used for the calculation of the bending rigidity B_{warp}, B_{weft} and B_{skew} respectively in the warp, weft and in skew directions.

Measurement of drape coefficient DC and node number N_{node}:

Modifications on the system of Cusick drapemeter (Figure 2) were made by the addition of an achievable application under Matlab in order to calculate the drape coefficient DC% [10]. Image analysis method was used to calculate the real surface of the drape to determine the numerical drape coefficient. This method is based on the passage by the original colour image to grey level image and finally to the binary one. The method of image processing for fabric drape measurement is characterised by the precision, speed and the ability to make various measurements.

The drape coefficient can be calculated using the following formula:

$$DC = \frac{\text{drape surface(pixel)} - \pi * (\text{supported disc ray(cm)} * c)^2}{\pi * (\text{total ray(cm)} * c)^2 - \pi * (\text{supported disc ray(cm)} * c)^2} \quad (2)$$

where: DC is the drape coefficient, c the correlation between the centimetre and the pixel.

The node number N_{node} here is calculated by the image analysis method.

Methods

The PCA is a powerful means of analysing quantitative data (continuous or discrete). This reliable method determines the weights for each image source by using the Eigen vector corresponding to the largest Eigen value of the covariance matrix.

The process phases for the PCA method for n variables correspond in a first step to calculate statistical variables, then to build a matrix of correlation of the variables and finally to calculate the Eigen values. The description of this method (steps and equations) is presented below.

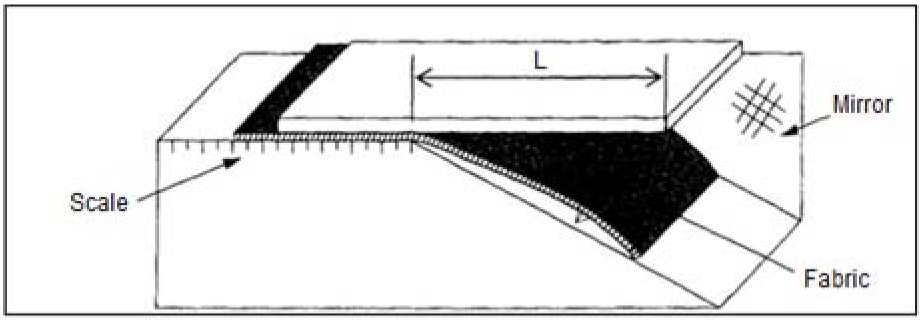

Figure 1. Principle of the flexometer method

Figure 2. The Cusick drapemeter

Statistics of the studied variables:

The average m_f is calculated using the following formula:

$$\boldsymbol{m_f} = \frac{1}{n}\sum_{i=1}^{n} \boldsymbol{x_{if}} \quad (3)$$

The average variance S_f is defined as:

$$\boldsymbol{S_f} = \frac{1}{n}\sum_{i=1}^{n} |\boldsymbol{x_{if}} - \boldsymbol{m_f}| \quad (4)$$

The standard deviation σ_f is given as:

$$\boldsymbol{\sigma_f} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\boldsymbol{x_{if}} - \boldsymbol{m_f})^2} \quad (5)$$

Matrix of the correlation of the variables:

In interpreting the principal components, it is often useful to know the correlations between variables. We start by calculating the variance $\boldsymbol{\sigma_f^2}$ which is defined as:

$$\boldsymbol{\sigma_f^2} = \frac{1}{n-1}\sum_{i=1}^{n}(\mathbf{x_{if}} - \mathbf{m_f})^2 \quad (6)$$

The covariance measures the joint dispersion of two random variables around their means and is defined as:

$$\mathrm{Cov}(x_i, m_k) = \frac{1}{n-1}\sum_{i=1}^{n}(x_{if} - m_f)(x_{ik} - m_k) \quad (7)$$

The correlation is defined as a measure of the dependence between two random variables x_i and m_k. The coefficients of linear correlation r_{ik} are concluded from equations (6) and (7) as:

$$r_{ik} = \mathrm{cor}(x_i, m_k) = \frac{\mathrm{cov}(x_i, m_k)}{\sqrt{\sigma_i^2 \ \sigma_k^2}} \quad (8)$$

where: i=1,2,.....n, k=1,2,......n, i ≠ k.

The correlation is checked by testing the following hypothesis:

When:
r is close to 1, the variables are significantly positively correlated.
r is close to 0, then the variables are not significantly correlated.
r is close to -1, *the* variables are significantly negatively correlated.

It's possible to build a matrix of correlation whose elements are the coefficients of linear correlation r_{jk}:

$$P = \begin{bmatrix} 1 & r_{12} & . & . & . & r_{1p} \\ r_{21} & 1 & & & & r_{2p} \\ . & & 1 & & & . \\ . & & & 1 & & . \\ . & & & & 1 & . \\ . & & & & & 1 \ . \\ r_{p1} & r_{p2} & . & . & . & 1 \end{bmatrix} \quad (9)$$

Calculation of Eigen values:

Eigen values are the weight of the corresponding axis; the decrease of the Eigen values and the variability leads us to consider only the first two principal axes. The Eigen value λ_k of the covariance is defined as:

$$\lambda_k = \sum_{j=1}^{d} \sigma_f^2 \ \mathrm{cor}^2(x_j, m_k) \quad (10)$$

Results and discussions

As seen in Table 1, bending rigidity in warp direction ranges from 0.040 to 23.654 μN.m, bending rigidity in weft direction ranges from 0.200 to 15.718 μN.m, bending rigidity in skew direction ranges from 0.08 to 32.406 μN.m, thickness ranges from 0.09 to 1.250 mm, fabric weight ranges from 65 to 366.6 g/m^2, drape coefficient ranges from 0.310 to 0.87 and node number ranges from 2 to 9.

The first interesting result to be analysed is the matrix of correlations (Table 2). It is found that not only the warp bending rigidity and the skew bending rigidity are correlated (r = 0.854) but also the thickness and fabric weight (r = 0.839). For a definite drape coefficient, different configurations (shadows) of the fabric and variations in the node numbers are obtained. Hence, a negative correlation between the drape coefficient and the node number is found. The node number is also negatively correlated to the three bending rigidities. It is found that the weft bending rigidity is slightly correlated with other variables. This indicates that the warp bending rigidity and the skew bending rigidity are the most influential properties.

As revealed in Table 3 and Figure 3, the Eigen values are fortunately related to a simple concept: the quality of the projection when changing dimensions of n (where n is the number of variables, here 7) to a smaller number of dimensions. In this case, the first Eigen value is 3.795 representing 54% of

Table 1. Characteristics of fabric samples

Variable	Minimum	Maximum	Average	Standard deviation
B_{skew}	0,080	32,406	2,144	4,787
B_{warp}	0,040	23,654	2,763	4,776
B_{weft}	0,200	15,718	1,885	3,048
W [g/m^2]	65,000	366,600	179,630	76,825
Thickness [mm]	0,090	1,250	0,488	0,222
DC	0,310	0,870	0,602	0,154
N_{node}	2,000	9,000	6,000	1,273

Table 2. matrix of correlations

Variables	B_{skew}	B_{warp}	B_{weft}	W[g/m^2]	Thickness [mm]	DC	N_{node}
B_{skew}	1	0,854	0,242	0,511	0,436	0,475	-0,658
B_{warp}	0,854	1	0,253	0,611	0,485	0,547	-0,637
B_{weft}	0,242	0,253	1	0,265	0,329	0,491	-0,388
W [g/m^2]	0,511	0,611	0,265	1	0,839	0,272	-0,270
Thickness [mm]	0,436	0,485	0,329	0,839	1	0,150	-0,149
DC	0,475	0,547	0,491	0,272	0,150	1	-0,684
N_{node}	-0,658	-0,637	-0,388	-0,270	-0,149	-0,684	1

Table 3. The Eigen values

	F1	F2	F3	F4	F5	F6	F7
Eigen values	3,795	1,383	0,929	0,373	0,257	0,150	0,113
Variability	54,213	19,751	13,269	5,332	3,678	2,149	1,607
Cumulated (%)	54,213	73,965	87,233	92,565	96,244	98,393	100,000

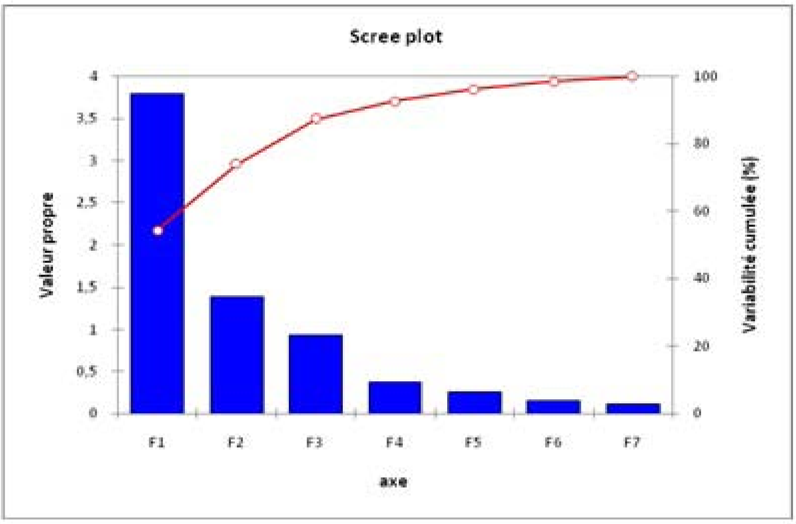

Figure 3. Scree plot

the variability. This means that if there are data on a single axis, then there will always be 54% of the total variability preserved.

Each Eigen value corresponds to a factor. Each factor is a linear combination of the original variables. The Eigen values and factors are listed in descending order of represented variability. Figure 3 enables us to select the axes for which the graphics should be displayed. In this case, the percentage of variability shown in the first two axes is high (73.965%).

In the literature, many parameters are cited as influencing the drape. Hu and Chan [11] found that bending rigidity, bending hysteresis, shear rigidity and weight are correlated with drape; they found also that bending hysteresis and bending rigidity are correlated. Lindberg *et al*. [12], Grosberg [8] and Oloffson [15] found that the most significant parameters correlating well with drape were bending rigidity and bending length. In this work, we measured bending rigidity in weft, warp and skew directions as well as thickness and weight (Figure 4). For a small change in thickness, we tested a significant variation in the drape coefficient (r =0.150) and node number (r=-0.149); these results prove that drape is slightly influenced by fabric thickness. The reason is due to the fact that the thickness has an effect on the flexural rigidity of the fabric – when the fabric thickness increases, drape becomes asymmetrical [4].

The chart below is one of the objectives of the PCA. It allows to represent fabrics from a two-dimensional map, and thus to identify trends. Figure 5 shows that fabrics T3, T5, T11 and Se11 are specific, as well as fabrics Se8, T9, T14 and T20, which have a high weight and a drape coefficient above the average.

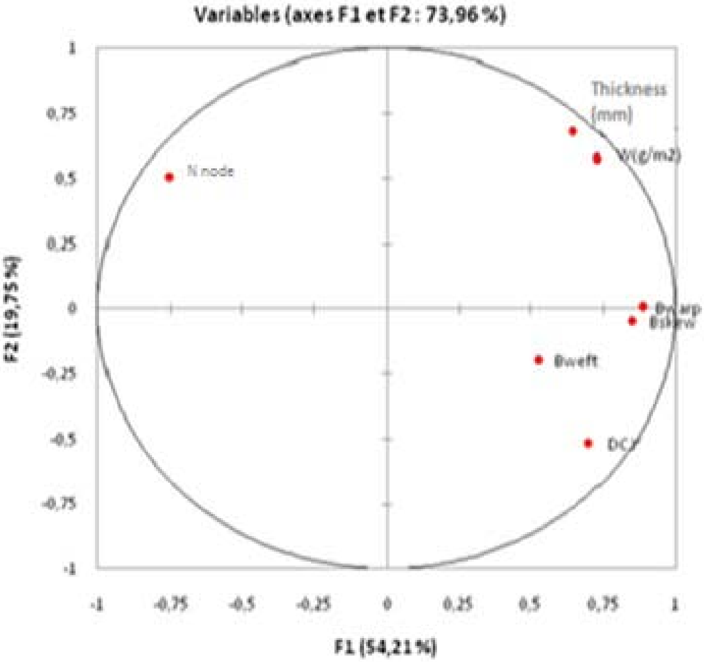

Figure 4. Circle of correlation between fabrics parameters and drape parameters

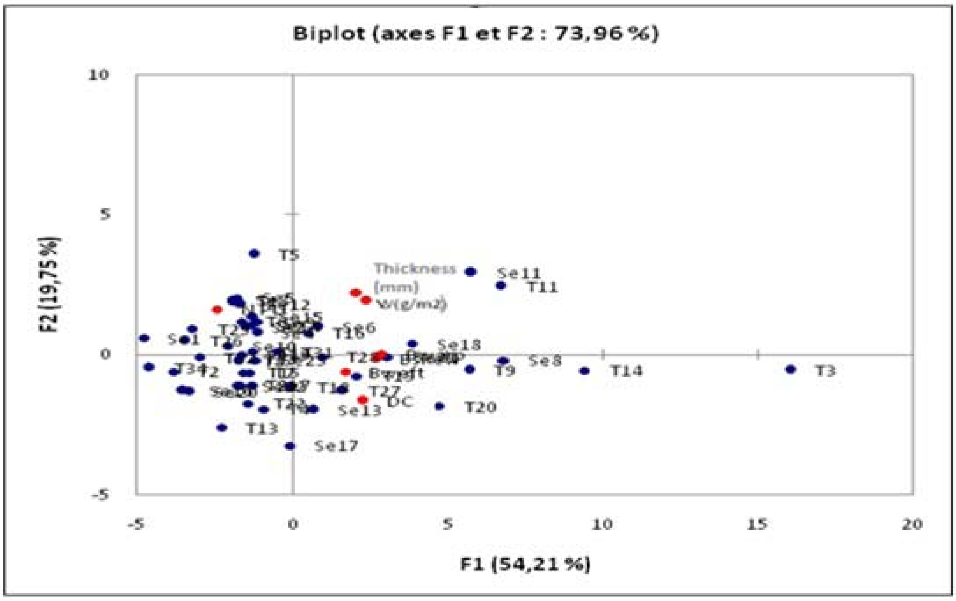

Figure 5. Plan of projection of the variables and the fabrics

The graph below is allowed to represent the parameters of a two-dimensional map.

Its aim is to provide approached plane images of the cloud of fabrics located in the space R^p. All the projections of all the points of the cloud of 55 fabric samples on the first factorial axis known as first factor represent new fabric parameters [17].

Conclusion

In the foregoing study, the use of the PCA method has been proposed and adopted for finding similarities and contrasts between some fabric parameters (thickness, weight and bending rigidity) and the drape parameters (drape coefficient and node number*)*. From the study and analyses, the following conclusions can be drawn:

- The proposed method has been found efficient for proving correlation between the drape and the bending rigidity and the weight, which confirms results found by Morooka and Niwa [9].
- The drape coefficient is negatively correlated to the node number.
- The node number is negatively correlated with the three bending rigidity parameters (bending rigidity in the warp, skew and weft directions).
- The warp bending rigidity is correlated with the skew bending rigidity.

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