**Chengxia Liu[1, 2,*]**
**Xiaoping Zheng[1, 2]**

# Comparative Investigation on Objective Evaluation Methods for Fabric Smoothness

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[1] **Zhejiang Sci-Tech University,**
Hangzhou, Zhejiang, China,
* e-mail: glorior_liu@hotmail.com

[2] **Zhejiang Province Engineering Laboratory of Clothing Digital Technology,**
Hangzhou, Zhejiang 310018, China

**Abstract**
*An objective method for fabric smoothness usually comprises two widely used approaches: 3D laser scanning and 2D image processing, which are represented by GLCM in this work. To make a comparison of them and find out which one is more effective, four 3D parameters (variance, roughness, torsion and interquartile deviation) and eight 2D parameters (mean value and standard deviation of energy, entropy, contrast and correlation) were extracted for AATCC SA replicas and fabrics. Results show that both 3D laser scanning and 2D image processing technology can be used to study smoothness. With regard to accuracy, the 3D laser scanning method is better than the 2D image processing method. Roughness in 3D parameters and the standard deviation of Entropy in 2D parameters have the highest correlation coefficient with the wrinkling grade of replicas, -0.965 and -0.917 respectively. The verification experiment of fabrics proves that roughness can characterise the wrinkling degree better as well. Furthermore, through the work of this paper, we find that the wrinkling degree differences between two adjacent AATCC SA replicas are not the same; the difference between SA-1 and SA-2 is significant, while that between SA-3 and SA-3.5 as well as SA-4 and SA-5 is not so obvious. It is advisable that the AATCC SA replicas for grades 3, 3.5, 4 and 5 be adjusted or improved.*

**Key words:** *AATCC replicas, 3D laser scanning, image processing, feature extraction, fabric smoothness.*

## Introduction

Fabric wrinkle after home laundering, also referred to as smoothness, plays very an important part in the appearance and overall quality of garments. Thus, it is of vital importance to characterise and quantify the smoothness level of fabric accurately. Until now, the most commonly used method is AATCC (American Association of Textile Chemists and Colorists) 124-2014 Test Method: Smoothness Appearance of Fabrics after Repeated Home Laundering. The AATCC 124-2014 Test Method is a subjective evaluation method conducted by a panel of experts. The panel compares fabric samples to be tested after home laundering with a set of three-dimensional AATCC SA (Smoothness Appearance) replicas, shown in ***Figure 1***, and decides the smoothness grade level of the fabric samples. There are 5 grade levels of the replicas, from SA-1 to SA -5 and in the middle of SA-3 and SA-4 there is SA-3.5. Hence, there are six SA replicas in total. However, there are some shortcomings in this subjective method, such as difficulty in discriminating between two adjacent grades and low efficiency [1, 2], as well as inconsistency among different experts, even for the same fabric samples.

With regard to these drawbacks of subjective evaluation, many methods using computers and other instruments have been devised to assess the smoothness grade more automatically, efficiently and objectively. Generally speaking, the methods used widely can be categorised as either 2D image technology or 3D laser technology.

In the early stage of development, many experts contributed various 2D image techniques. Xu.B [3] defined two variables, surface ratio and shade ratio, to quantify wrinkled appearance. Kang [4] used fractal geometry to objectively evaluate the surface ruggedness of fabric wrinkles and seam puckers. Toshio Mori [5] extracted the angular second moment, contrast, correlation, and entropy from the gray level co-occurrence matrix as visual feature parameters. Jinlian Hu [6] used the photometric stereo method to extract three-dimensional surfaces and image analysis techniques to extract wrinkling features. M. Mohri [7] utilised an image analysis technique using the radon transform (RT) and texture analysis to evaluate wrinkling. Kang [8] proposed a wavelet-fractal method to objectively evaluate the surface roughness of fabric wrinkle, smoothness appearance and seam pucker. Ravanidi SAH and Pan N [9] analysed the influence of grey-level co-occurrence matrix variables on the textural features of wrinkled fabric surfaces. In recent years, Liu proposed a novel method [10] for fabric wrinkle resistance simulating actual wear, and used the fractal dimension to describe wrinkling. After that, a novel method for multidirectional fabric wrinkling measurement [11] was presented and wavelet analysis used to characterise fabric wrinkling.

The study of fabric smoothness using 3D technology is not so wide as that of 2D image technology. B. Xu [12] reported the basic principle of laser triangulation for extracting surface profiles and wrinkle characterisation methods. Kang [13] used a laser scanning system and obtained the surface contours of wrinkled fabrics. N Abidi [14] validated a system for the automatic grading of fabric smoothness, which consisted of a sheet-of-light, a laser-line projector, a smart CMOS camera, and a moving platform. Mir Saeed Hesarian [15] studied the wrinkle property of fabrics using the projected profile light line technique.

Summarising the above, we find that researches on fabric smoothness until now have carried out either by 2D image processing or by 3D laser technology. In other words, in each study, only one single approach is used. It is still unknown to us which method is more accurate and effective, since no such investigation has been made in which two methods are utilised on the same samples. Therefore, we carried out this research to compare and analyse quantificationally the two objective methods widely used for fabric

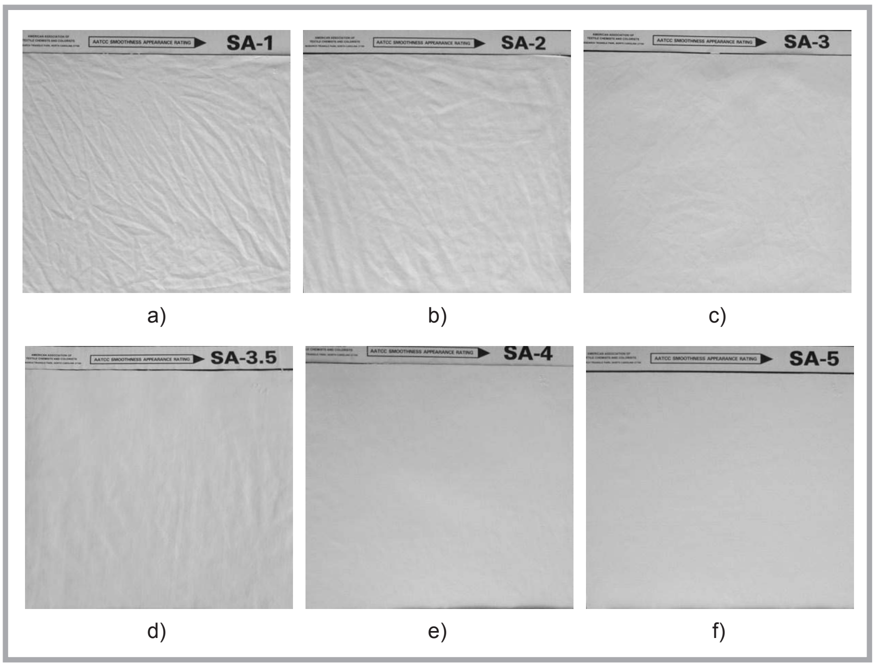

*Figure 1. AATCC 124 smoothness appearance replicas: a) SA-1, b) SA-2, c) A-3, d) SA-3.5, e) SA-4, f) SA-5.*

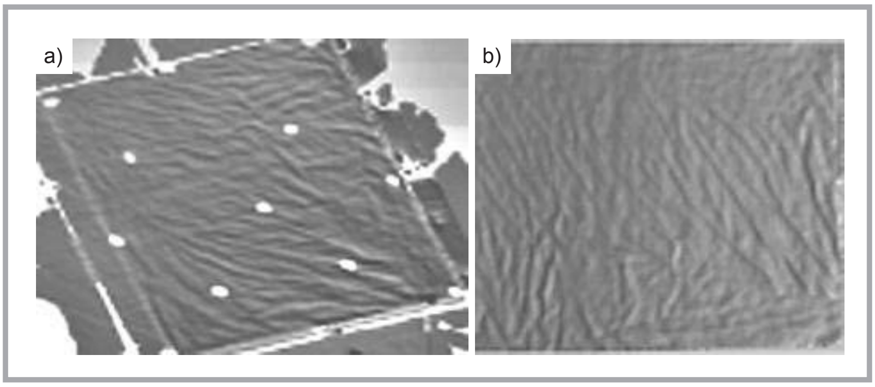

*Figure 2. 3D reconstruction of replica surface for grade 1: a) untreated reconstructed image, b) pre-processed reconstructed image.*

smoothness, the result of which may be helpful and advisable for objective and accurate evaluation.

## Experimental

### 3D laser scanning of AATCC replicas

A Handy Rescan 3D laser scanning system, developed by Creaform Co, Canada, was used to acquire original cloud points data of the AATCC replicas standard. The equipment can scan 18000 times/second and the scanning accuracy can reach as high as 0.05 mm. The equipment possesses the following advantages: by using an optical reflecting target, the reference system of the equipment can be formed and locked. As a result, during the scanning process, the scanning together with the object being scanned can be moved without the support of a rail. Besides this, 3D scanning data are displayed on the screen of the computer at the same time as scanning. After having scanned for a while, you can stop and observe the results of the scanned parts on the screen. If there are some parts the scanner cannot reach, you can adjust it. After finishing this, scanning can be continued, without repeated data acquisition.

After the six AATCC replicas had been scanned, the .txt cloud data acquired were inputed into Geomagic Studio software. A replica of grade 1 is given as an example, with the surface of its untreated 3D reconstructed image shown in ***Figure 2.a***. The pre-processed image after de-noise, filling holes, cutting, etc, is shown in ***Figure 2.b***. From ***Figures 2.a*** and ***2.b***, we can see that the pre-processed reconstructed image retains the original wrinkles.

### Parameter extraction of AATCC SA replicas

The following parameters were extracted for six reconstructed replicas from the cloud data obtained.

Variance *V*: $$V = \frac{1}{n}\sum_{i=1}^{n}\left(Z_i - \overline{Z_i}\right)^2 \quad (1)$$

where, $Z_i$ is the height value of each point on the surface of the replica, *n* the number of points and $\overline{Z_i}$ the mean height value of all the points.

Roughness *R*: $$R = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Z_i - \overline{Z_i}\right)^2} \quad (2)$$

Torsion *T*: $$T = \frac{1}{n}\sum_{i=1}^{n}\left(Z_i - \overline{Z_i}\right)^3 \Big/ R^3 \quad (3)$$

Interquartile deviation *ID*:

$$ID = Qu - Qv \quad (4)$$

where, *Q*u is the height value at the position of the bottom 25%, and *Q*v is the that at the position of the top 25%, after arraying the height value of each cloud point from small to large. *ID* is the difference between *Q*u and *Q*v, which represents the deviation of the middle 50% data. The smaller the value is, the more concentrated the middle data are.

### Parameter extraction of replicas using 2D image processing

As has been stated above, many image processing methods have been applied to fabric smoothness. Among these, the grey level co-occurrence matrix (GLCM) is widely used, which has a very high correlation with fabric smoothness [5, 16]. GLCM is defined as the probability *p*(*i*, *j*) of a pixel of grey-level *i* occurring in the specified spatial relationship of (*d*, θ) with a grey-level *j*, in which *d* and θ are the distance and positional angle between the two grey-level pairs (*i*, *j*). Conventionally, the positional angle comprises 0°, 45°, 90° and 135°. Because of the limited length of the paper, it is not possible to list all the extraction results used by every image processing method here. Therefore, the grey level co-occurrence matrix is just taken as an example of image processing technology to do comparative research with the 3D laser scanning method.

Images of the six replicas were acquired with a digital camera, cut to 400 pixel × 400 pixel, and then converted into a grey-level image. To improve the computational efficiency, the images were monochromatic with 16 grey levels, and d was 1.

Four parameters: energy, entropy, contrast and correlation, in the direction of 0°, 45°, 90° and 135°, were extracted. These parameters are the most commonly used GLCM variables for fabric smoothness characterisation. The meanings of the four parameters are as follows:

Energy, calculated according to ***Equation (5)***, measures the textural homogeneity.

$$Energy = \sum_i \sum_j \{p(i,j)\}^2 \quad (5)$$

where, $p(i, j)$ is the probability of a pixel of grey-level $i$ occurring in the specified spatial relationship with a grey-level $j$, $i, j = 0, 1,..., N\text{-}1$, $N$ — number of grey levels in the image.

Entropy, calculated according to ***Equation (6)***, indicates the disorder of the texture.

$$Entropy = -\sum_i \sum_j p(i,j) \log\{ p(i,j)\} \quad (6)$$

where, $p(i, j)$ has the same meaning as that in ***Equation (5)***.

Correlation, calculated according to ***Equation (7)***, represents the linear dependency between grey levels in the texture.

$$Correlation = \frac{\sum_i \sum_j (ij) p(i,j) - \mu_x \mu_y}{\delta_x \delta_y} \quad (7)$$

where,

$$\mu_x = \sum_i i \sum_j p(i,j),\ \mu_y = \sum_j j \sum_i p(i,j),$$

$$\delta_x^2 = \sum_i (i-\mu_x)^2 \sum_j p(i,j),$$

$$\delta_y^2 = \sum_j (j-\mu_y)^2 \sum_i p(i,j).$$

Contrast, calculated according to ***Equation (8)***, reflects the local variations of texture:

$$Contrast = \sum_i \sum_j (i-j)^2 p(i,j) \quad (8)$$

where, $p(i, j)$ has the same meaning as that in ***Equation (5)***.

Then, the mean value (M) and standard deviation (S) of the four parameters are calculated. Take energy as an example.

$$\overline{Energy} = \frac{Energy_{0°} + Energy_{45°} + Energy_{90°} + Energy_{135°}}{4} \quad (9)$$

***Equation (9).***

***Equation (9)*** where, Energy is the mean value of Energy in the four directions; $Energy_{0°}$, $Energy_{45°}$, $Energy_{90°}$ and $Energy_{135°}$ represent the energy in the directions of 0°, 45°, 90° and 135°, respectively.

$$SE = \sqrt{\frac{1}{4}\sum_{i=1}^{4}(x_i - \mu)^2} \quad (10)$$

where, SE is the standard deviation of Energym $x_1$ – $Energy_{0°}$, $x_2$ – $Energy_{45°}$, $x_3$ – $Energy_{90°}$, and $x_4$ is $Energy_{135°}$.

Using the same method, eight parameters, i.e. the mean value and standard deviation of energy, entropy, contrast and correlation, were obtained.

### Verification with fabric samples

16 woven fabrics, listed in ***Table 1***, were chosen to perform a validation test to verify which ones, 2D parameters or 3D parameters, can distinguish fabrics with different wrinkle severity levels more effectively. The fabrics chosen were subjected to home laundering and drying treatment according to AATCC Test Method 124-2014, then the treated samples were graded using the AATCC smoothness appearance replicas, and subsequently parameters were immediately extracted with the two methods above: 3D laser scanning and 2D image processing.

Subjective evaluation was conducted by a panel of 5 experienced experts coming from the quality control field. The evaluation results of the 5 experts were found to be in good agreement. Lastly, the subjective evaluation results were averaged and rounded up to be the final wrinkling grade number in accordance with the grade level of AATCC SA replicas.

## Results and discussion

### Relationship between 3D parameters and the wrinkling grade of replicas

Parameters of the six AATCC replicas using three-dimensional laser scanning technology, 3D parameters in short, are shown in ***Figure 3***, from which, we can see that the torsion $T$ does not show a very obvious trend with the wrinkling grade. Except for torsion, there is very similar relationship between 3D parameters and the wrinkling grade for the variance $V$, roughness $R$ and interquartile deviation $ID$. With an increasing in the grade level of the replicas, the three parameters extracted: variance, roughness and interquartile deviation, clearly decrease. Parameters for SA-1 are the highest, while those for SA-5 are the lowest, which agree well with the fact that the SA-1 replica has the most severely wrinkled surface and the SA-5 replica has the smoothest surface. It is well known that the wrinkling or smoothness degree

*Table 1. Parameters of fabrics.* ***Note:*** *C: cotton, L: linen, S: silk, W: wool, P: polyester.*

| Fabric | Colour | Weave | Fibre content | Density (/10cm), warp×weft | | Mass per unit area, g/m$^2$ | Thickness, mm |
|---|---|---|---|---|---|---|---|
| F1 | green | plain | 55 L/45C | 211 | 203 | 82 | 0.25 |
| F2 | yellow | plain | 100% L | 180 | 152 | 80 | 0.21 |
| F3 | red | twill | 100% P | 135 | 110 | 116 | 0.34 |
| F4 | cream | plain | 50S/50P | 218 | 200 | 68 | 0.15 |
| F5 | print | twill | 100% C | 100 | 87 | 151 | 0.36 |
| F6 | orange | twill | 80W/20P | 222 | 220 | 65 | 0.15 |
| F7 | brown | plain | 100% S | 100 | 87 | 151 | 0.48 |
| F8 | blue | plain | 160L/40C | 256 | 230 | 125 | 0.35 |
| F9 | gray | twill | 100% W | 188 | 172 | 88 | 0.24 |
| F10 | pink | plain | 65 C/35P | 150 | 108 | 280 | 0.65 |
| F11 | purple | satin | 100% S | 156 | 139 | 128 | 0.29 |
| F12 | gray | plain | 70 L/30C | 105 | 83 | 128 | 0.32 |
| F13 | print | twill | 100% W | 75 | 49 | 226 | 0.52 |
| F14 | khaki | plain | 65 C/35P | 136 | 70 | 237 | 0.49 |
| F15 | Yellow | satin | 100% S | 119 | 31 | 60 | 0.21 |
| F16 | White | plain | 70 L/30C | 51 | 39 | 70 | 0.37 |

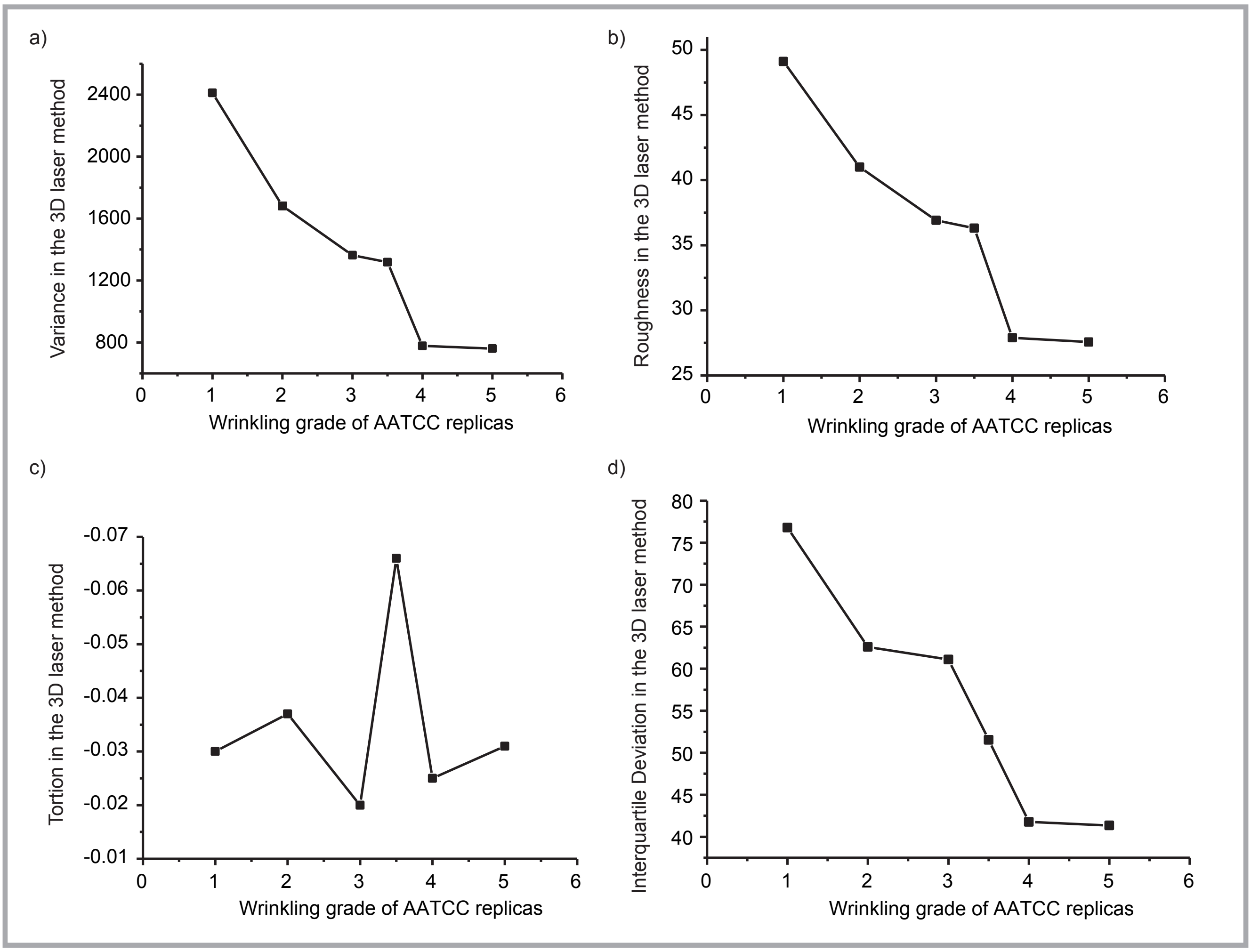


***Figure 3.** Relationship between 3D parameters and wrinkling grade replicas: a) Variance V, b) Roughness R, c) Torsion T, d) Interquartile Deviation ID.*

can be characterised by the height deviation of the replica surface, which is just the common meaning of variance, roughness and interquartile deviation from ***Equations (1)***, ***(2)*** and ***(4)***.

However, ***Figure 3*** also indicates that the value differences between two adjacent replicas are not the same. From ***Figure 2***, the wrinkling difference between SA-1 and SA-2 is relatively obvious, while that between SA-4 and SA-5 is very subtle. We can compare the wrinkling difference between adjacent replicas together with ***Figure 1***. From ***Figure 1***, we can observe that the wrinkling difference between SA-1 and SA-2 is the most significant, and that between SA-2 and SA-3 is also distinct. However, the wrinkling difference between SA-3 and SA-3.5 as well as SA-4 and SA-5 is not so evident. Therefore, it may be hard to discern the subtle difference between SA-4 and SA-5 in actual subjective evaluation. Besides, the difference between a grade of 3 and 3.5 is not very clear either.

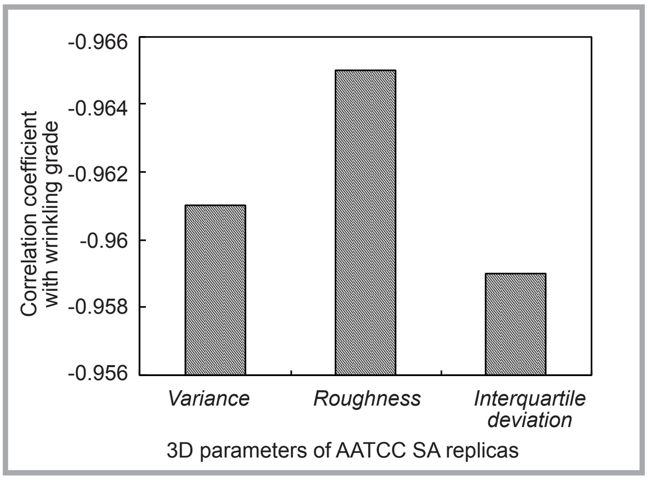


***Figure 4.** Correlation coefficients between 3D parameters and the wrinkling grade of replicas.*

To deeply understand the relationship between the wrinkling grade of AATCC SA replicas and 3D parameters variance *V*, roughness *R* and interquartile deviation *ID*, a correlation analysis of them is made, whose result is shown in ***Figure 4***. From this we can clearly see that roughness *R* has the highest correlation coefficient (-0.965) with the wrinkling grade of replicas, with *V* second (-0.961) and *D* the lowest(-0.959). To sum up, of the four parameters extracted with 3D laser scanning technology, *R* can characterise the wrinkling surface of the six grades of SA replicas best.

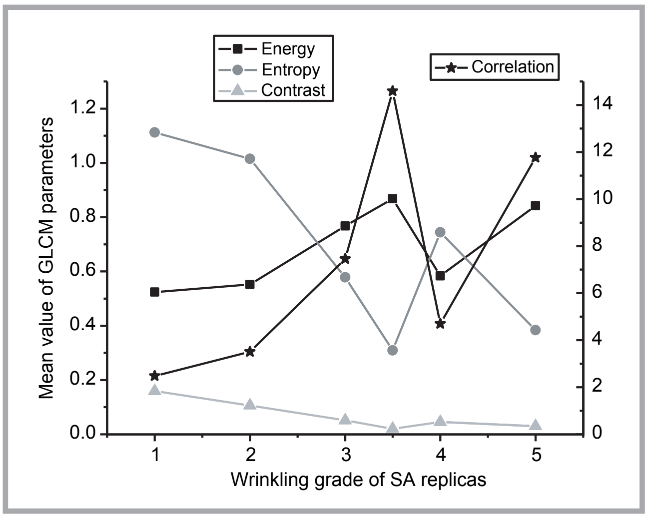


*Figure 5. Relationship between mean values of GLCM parameters and the wrinkling grade.*

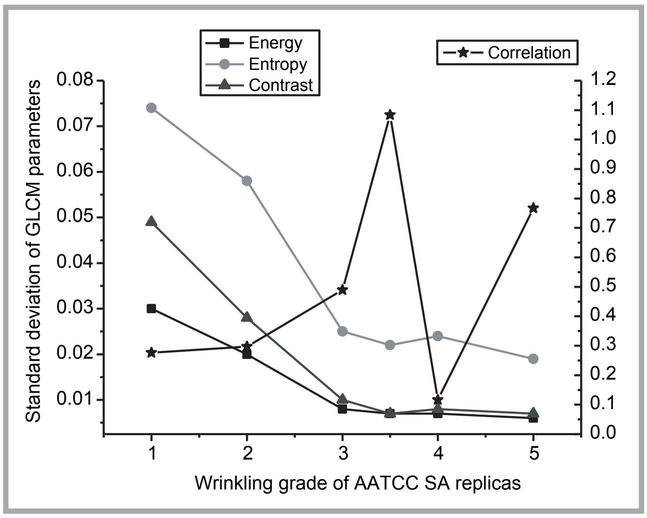


*Figure 6. Relationship between the standard deviation of GLCM variables and the wrinkling grade*

### Relationship between 2D parameters and wrinkling grade of replicas

***Figure 5*** shows the mean values of four GLCM parameters extracted for six replicas (including SA-3.5), from which we can see that of the four parameters, energy and correlation show a similar increasing tendency, while entropy and contrast show a decreasing tendency with an increase in the wrinkling grade, except grades of 3.5 and 4. Take grade 1 and energy as an example. As has been mentioned above, energy measures textural homogeneity; SA-1 has the most severe wrinkling surface, thus its textural homogeneity is the worst, as a result of which, the mean value of energy for SA-1 is the lowest. However, SA-3.5 and SA-4 do not obey this rule, the result of which is that the line charts are not in good order.

***Figure 6*** shows the standard deviation of four GLCM parameters extracted for six replicas. From this we can see that except correlation, the other parameters show a similar tendency i.e. decreasing with an increase in the wrinkling grade. To be more precise, the standard deviation of energy, entropy and contrast decreases sharply from SA-1 to SA-3 and decreases rather slowly from SA-3 to SA-5. In other words, for SA-3, SA-3.5, SA-4 and SA-5, the difference in value of standard deviation is subtle, which corresponds with what we have seen in ***Figure 1***.

To obtain a further understanding of the relationship between the wrinkling grade of the SA replicas and GLCM parameters, a correlation analysis was made, whose result is shown in ***Figure 7***. In this, M is the mean value and S the standard deviation. From ***Figure 7***, we can see that there is positive correlation between the wrinkling grade and the mean value of energy and correlation. Also, the standard deviation of the correlation with the wrinkling grade is positive. All the parameters left have a negative correlation with the wrinkling grade, which agrees with ***Figure 5*** and ***Figure 6***. With regard to the correlation coefficient value, the highest is S (standard deviation) of entropy (-0.917), the second S of energy (-0.910). Besides this, ***Figure 7*** shows that S (standard deviation) of the four GLCM parameters has a higher correlation with the wrinkling grade than M (mean value), except correlation.

Comparing ***Figure 7*** with ***Figure 4***, we can clearly ascertain that 3D parameters (correlation coefficients with the wrinkling grade are over -0.96) have a higher correlation with the wrinkling degree of the replicas than GLCM (the highest correlation coefficient with the wrinkling grade is -0.917).

### Relationship between objective parameters and subjective evaluation of fabrics

Next, whether the objective parameters above (including 3D parameters and GLCM parameters) can characterise the wrinkling degree of fabrics or not and which one is better at characterising will be further investigated. Since roughness *R* is the best one in 3D parameters and the standard deviation of Entropy in GLCM parameters, as analysed above, they are taken as examples to make a comparison and description. The wrinkling degree of the 16 fabrics is subjectively evaluated,

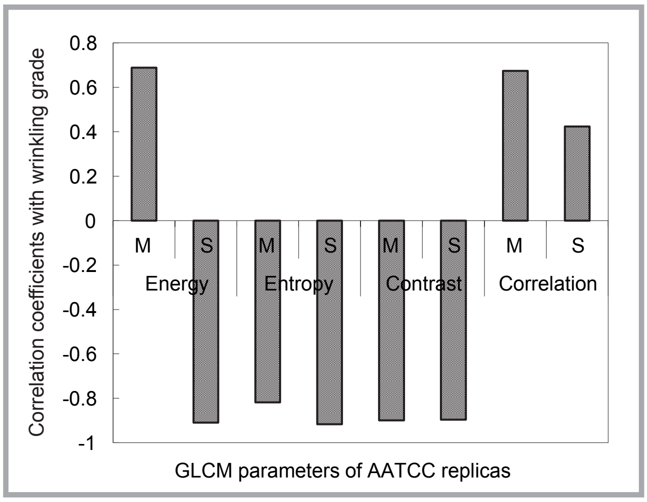


*Figure 7. Correlation coefficients between the wrinkling grade of replicas and GLCM parameters.*

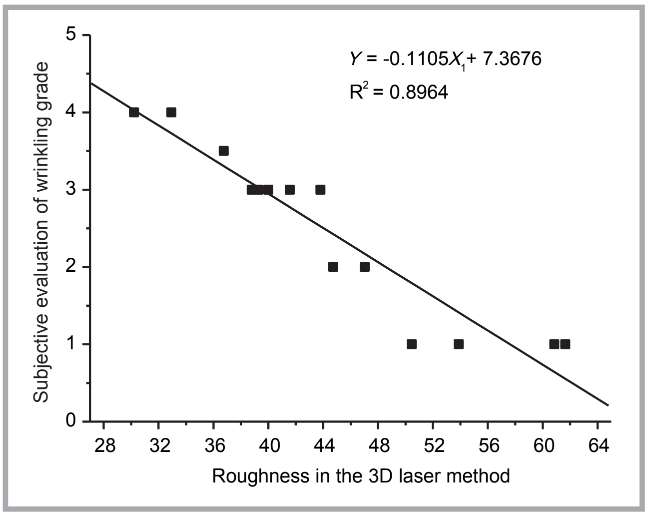


*__Figure 8.__ Relationship between the subjective wrinkling grade and roughness of fabrics.*

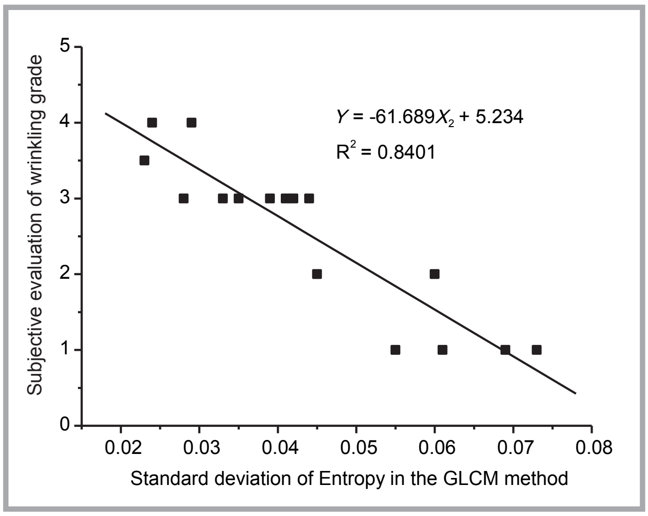


*__Figure 9.__ Relationship between the subjective wrinkling grade and standard deviation of entropy.*

with grade 5 the best smoothness and grade 1 the worst. Results of the objective 3D roughness parameter and 2D parameters: standard deviation of entropy and the subjective wrinkling grade are listed in ***Table 2***.

Correlation coefficients of objective parameters and the subjective grade of 16 fabrics are shown in ***Table 3***.

From ***Table 3***, we can see that both the roughness and standard deviation of energy have a significant negative correlation with the subjective wrinkling grade. That is, both the 3D scanning technology and 2D image processing technology can be used to evaluate the wrinkling degree of real fabrics of different colour, weave, etc. As for the accuracy, the 3D scanning method is better than the 2D image processing method, as the 3D roughness parameter (-0.947) has a higher correlation coefficient with a subjective grade than the 2D standard deviation of energy (-0.917) parameter does.

Next a linear analysis was conducted to establish the exact equation between the subjective grade with roughness and the standard deviation of energy. ***Figures 8*** and ***9*** show the results.

From the two figures, we can see that roughness has a higher correlation with the subjective wrinkling grade, i.e. roughness in the 3D laser method can characterise the wrinkling degree of fabrics better than the standard deviation of entropy in the GLCM method, which is the same as for the AATCC SA replicas. It can be explained by the fact that 3D laser scanning technology can obtain the vertical height of each point on the surface of wrinkled fabrics, which can reflect the wrinkling degree relatively accurately, no matter what colour or pattern the fabric has. However, when t wrinkled fabrics are analysed by image processing technology, represented by GLCM in this work, the extraction results may be affected by the fabric texture, colour, pattern, etc. As to whether the shadow is caused by wrinkling or by the fabric pattern cannot be distinguished by image processing technology; it may be difficult for 2D image processing technology to reach the same accuracy as 3D laser scanning technology. Despite this, 2D image processing technology does have its advantages, such as lower cost.

Even if roughness can describe the wrinkling degree of fabrics relatively well, the data dots in ***Figure 7*** are not so focused around the fitting line. This may be caused by the fact that there are six grades altogether in AATCC replicas; thus, even if the fabrics are classified into the same grade, they may have a different wrinkling surface. Moreover, the differences between grade 3 and 3.5 as well as grade 4 and 5 are so subtle that it is difficult to discriminate the exact grade when subjective evaluation is carried out. Furthermore, the colour and pattern of fabrics may also influence the subjective results.

Furthermore, from ***Figure 7*** and ***Figure 8***, we obtain equations between the

*__Table 2.__ Parameters of fabrics.*

| Fabric | Roughness | Standard deviation of energy | Subjective grade | Fabric | Roughness | Standard deviation of energy | Subjective grade |
|---|---|---|---|---|---|---|---|
| F1 | 39.06 | 0.042 | 3 | F9 | 40 | 0.033 | 3 |
| F2 | 41.57 | 0.044 | 3 | F10 | 32.94 | 0.024 | 4 |
| F3 | 38.79 | 0.028 | 3 | F11 | 39.28 | 0.039 | 3 |
| F4 | 60.85 | 0.069 | 1 | F12 | 39.15 | 0.035 | 3 |
| F5 | 36.75 | 0.023 | 3.5 | F13 | 44.74 | 0.045 | 2 |
| F6 | 30.22 | 0.029 | 4 | F14 | 47.028 | 0.06 | 2 |
| F7 | 43.81 | 0.041 | 3 | F15 | 50.46 | 0.055 | 1 |
| F8 | 61.66 | 0.073 | 1 | F16 | 53.892 | 0.061 | 1 |

*__Table 3.__ Correlation coefficients of objective parameters and subjective grade of fabrics. __Note:__ **means the correlation is significant at the 0.01 level.*

| Parameter | Subjective grade | Roughness | Standard deviation of energy |
|---|---|---|---|
| Subjective grade | 1 | -0.947** | -0.917** |
| Roughness | | 1 | -0.942** |
| Standard deviation of energy | | | 1 |

subjective wrinkling grade and roughness:

$$Y = -0.1105X_1 + 7.3676 \quad (11)$$

$$Y = -61.689X_2 + 5.234 \quad (12)$$

where, $Y$ is the subjective wrinkling grade, $X_1$ roughness in the 3D laser method, and $X_2$ is the standard deviation of energy in the 2D image processing method.

These two equations can be used to predict the subjective winkling grade with two objective parameters after 3D laser scanning and 2D image processing.

## Conclusions

AATCC 124 SA replicas were studied and analysed with 3D laser scanning and 2D image processing technology, as a result of which the following 3D parameters: variance $V$, roughness $R$, tortion $T$ and interquartile deviation $ID$, as well as the following 2D GLCM parameters: the mean value and standard deviation of energy, entropy, contrast and correlation were extracted. Then the procedures above were conducted for 16 woven fabrics with different fibre contents and weave structures to verify the result. Results show that for the AATCC SA replicas, the standard deviation of four GLCM parameters has a higher correlation with the wrinkling grade than their mean value , except the correlation. The roughness $R$ in the 3D parameters and the standard deviation of entropy in the 2D GLCM parameters are the ones that have the highest correlation coefficient with the wrinkling grade of the AATCC SA replicas: -0.965 and -0.917 respectively. Verification of the fabrics proves that roughness $R$ can also characterise the wrinkling degree of fabrics better than the standard deviation of entropy.

To sum up, both 3D laser scanning technology and 2D image processing technology can be used to study the smoothness of replicas and fabrics. With regard to the accuracy, 3D laser scanning technology is better than the 2D image processing technology, which is represented by GLCM in this work. With the improvement of science and technology, the reduced cost of a 3D laser scanner would lead to the wider application of 3D laser scanning technology in the fabric performance measurement field.

Furthermore, through the work of this paper, we find that the wrinkling difference of AATCC SA replicas between two adjacent grades is not the same, of which grade SA-1 and SA-2 are the most distinct in the wrinkling degree. But the wrinkling difference between SA-3 and SA-3.5 is not so obvious, while that between SA-4 and SA-5is subtle. This may cause difficulty in determining the exact wrinkling grade in actual subjective evaluation. Therefore, it is advisable that the AATCC SA replicas for grades 3, 3.5, 4 and 5 be adjusted or improved for more convenient and accurate subjective evaluation.


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