

Objective Evaluation Method for Appearance of Fabric Wrinkling Replica by Image Processing System

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Received on 25 July 2001; Accepted for Publication on 1st December 2001

ABSTRACT

This paper describes the method evaluating the appearance of fabric-wrinkling replicas objectively by image processing. Results indicate that the wrinkle can be reliably measured using the distribution of gray level and the ratio of surface area, the ratio of X-direction length and the one of Y-direction length of surface profiles. All parameters with wrinkling fall on good logarithmic functions, which have high correlation coefficients. All parameters used can quantify the wrinkle of replicas with AATCC grades. The profile lines of surface are also analyzed with the method of Fast Fourier Transform.

Keywords: Wrinkle, Image processing, Objective evaluation, Fast Fourier Transform

1. Introduction

Wrinkle resistance of fabrics is one of most important factors, which affects the aesthetic and easy care properties of clothing. Monsanto method, Sun-Ray Test method and AATCC test method 128 are widely used in evaluating the wrinkle resistance of fabrics [1-3]. The wrinkle recovery standard replicas of AATCC show five grades of wrinkling from grade 1, which represents a deep wrinkle appearance or the highest degree of wrinkling, to grade 5, which does an almost absolutely flat surface or the slightest. Because AATCC method is a subjective evaluating one on the basis of human experts, its results are often affected by some subjective factors. In addition, there are unequal intervals in the degree of wrinkling in replicas. Thus, more objective and precise evaluating methods should be used in assessing the fabric wrinkle by image processing system.

Image processing system has been developed for evaluating wrinkle appearance of certain fabrics. There have been several researches and efforts to evaluate it [4-9]. Among of them, a simple method for measuring wrinkling density or shaded area of fabrics would involve computing area coverage due to shadows created by wrinkles. This method requires a binary (black and white) image. Because the choice of threshold is arbitrary, the

results are not independent of the method and the value chosen and are especially subjected to biases when illumination is not uniform or in presence of noise or intensity gradients.

In this study, the standard deviation of gray level intensity G_{sd} , the ratio of surface area R_A , the ratio of X-direction length R_{Lx} and the one of Y-direction length R_{Ly} of surface profiles are defined and used in evaluating the wrinkling appearances of fabrics. The wrinkles of surface profiles and their spectra are also analyzed with Fast Fourier Transform (FFT).

2. Experimental Equipment and Methods

The image processing system is shown in Figure 1. Each AATCC replicate is illuminated from top by three standard FL20SN-EDL-NU fluorescent lights in a small dark room and the illumination on its surface in horizontal plane is 756 lx. The incident lighting angle (ϕ) can be adjusted from 40° to 85° . Images are captured perpendicular to the optical axis of the camera. Digitization is done on a capture board installed in an NEC computer. Images are captured using a spatial resolution of 351×351 pixels, corresponding to approximately 80×80 mm in actual area in the center of fabric, and a pixel depth of 8 bits (256 shades of gray). Because noise exists in the captured image, which is

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produced from illumination reflection, camera imperfections, surface texture and structure of fabrics, all images are filtered using a 7×7 weighting and smoothing filter. Figure 2 shows the images that are un-filtered and filtered for representative three standard replicas. Noise with high frequency signals has been wiped off and images are smoothed without adversely affecting the signals due to wrinkling.

3. Characterization of Wrinkling

The underlying assumption in this study is that the digitized intensities are proportionally related to the height and wrinkle of the surface features. Model of calculating the gray level is illustrated in Figure 3, where intensity is plotted as the height or the Z-axis. In all cases, intensity is quite predicative of the degree of surface wrinkling as indicated by the AATCC replicate grading system. A horizontal direction pixel is referred to as the X-axis, a vertical direction pixel as the Y-axis. The wrinkle properties can be judged by means of analyzing the gray levels of images and are depicted using the distribution of gray level G_{sd} , the ratio of surface area R_A , the ratio of X-direction length R_{Lx} and the one of Y-direction length R_{Ly} of surface profiles. The wrinkle can be clearly reflected by the amplitudes, peaks and frequencies with FFT.

3.1 Standard Deviation of Gray Level G_{sd}

A smooth fabric is expected to exhibit a uniform appearance, resulting in a narrow gray level histogram and a low standard deviation. When the wrinkle of fabrics is increased, the reflection light angle is varied to each dot in the surface of fabric. The brightness is increased and gray level is also larger in one of them. On others, the brightness is decreased and gray level is also lower in others. And so, shadows are created by wrinkles. Although the mean of gray level in the measured area range is slightly changed, distribution of gray level is obviously varied with increasing of wrinkle. Standard deviation of gray level (G_{sd}) is defined as

$$G_{sd} = \sqrt{\frac{\sum \sum (Z_{(i,j)} - \bar{Z})^2}{m \times n}} \quad (1)$$

where $Z_{(i,j)}$ is the gray level of point $A(i,j)$, \bar{Z} the mean of data points and m, n the pixels in X direction and Y direction separately.

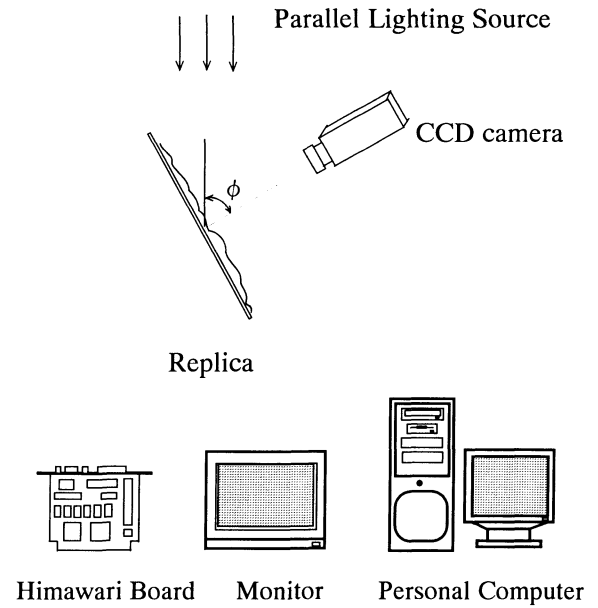


Fig. 1 Image analysis system of fabric wrinkle

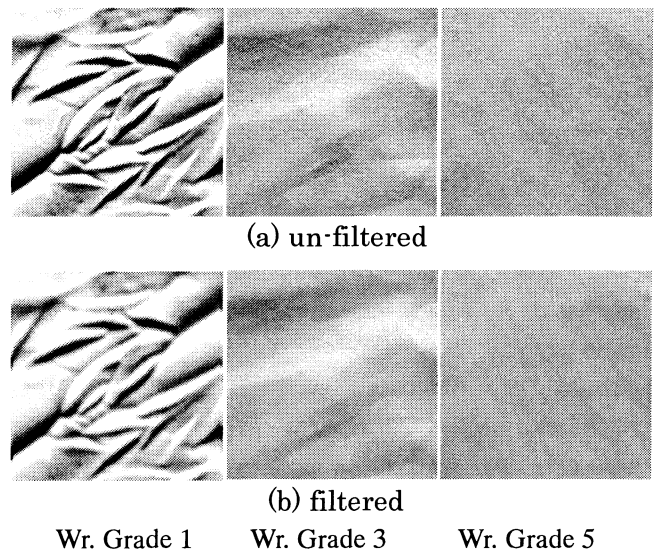


Fig.2 Images of replicas

3.2 Ratio of Surface Area R_A

Surface area chiefly depends on the shape of surface, and indicates a measure of wrinkle grade based on intensity variation. A completely smooth image, that is, an image that has no intensity difference of gray level among the entire pixels, will have a minimal surface area that equals the area of the image square.

The surface area appears to be larger with wrinkling. To calculate surface area, four adjacent pixels (points A, B, C and D) sharing one quadrilateral are first selected. When the intensities of four pixels are same, quadrilateral has the minimal area, which is equal to the projection

area in X-Y plane. The intensities will bring about changing with wrinkling. The surface area is larger than that of the projection area in X-Y plane, because their four vertexes (A', B', C' and D') may not be in same horizontal plane. Area of four adjacent pixels can be calculated by

$$S_{\square A'B'D'C'} = S_{\Delta A'C'D'} + S_{\Delta A'B'D'} \quad (2)$$

The sum surface area is calculated by summing individual quadrilateral. Thus

$$S = \sum_1^n \sum_1^m S_{\square A'B'D'C'} \quad (3)$$

where m, n are the pixels in X direction and Y direction, respectively.

Ratio of surface area R_A is defined as the ratio of surface area (S) to the total orthogonal projection area (S_p) of surface area in X-Y plane.

$$R_A = \frac{S}{S_p} = \frac{\sum_1^n \sum_1^m S_{\square A'B'D'C'}}{(x_m - x_1)(y_n - y_1)} \quad (4)$$

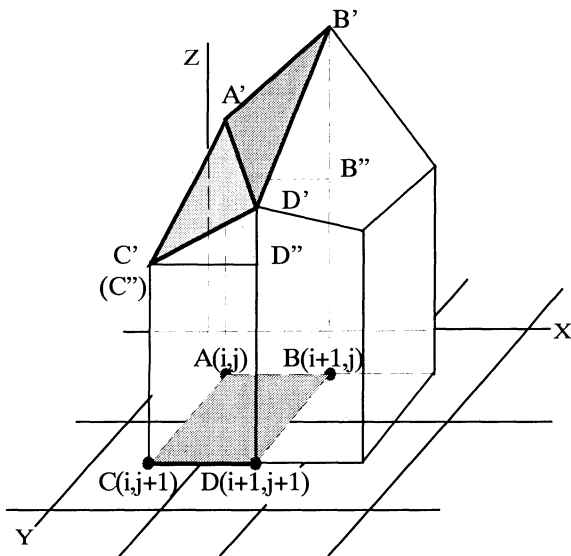


Fig.3 Model of calculating gray level

3.3 Ratio of X-direction Length and Y-direction Length of Surface Profiles

According to the appearance of fabrics after induced wrinkling with Wrinkle Recovery Tester of AATCC, The X-direction length and the Y-direction length of surface profiles will be different. R_{Lx} or R_{Ly} is defined as follows:

$$R_{Lx} = \frac{\sum \sum L_{A'B'}}{n(x_m - x_1)} \quad (5)$$

$$R_{Ly} = \frac{\sum \sum L_{A'C'}}{m(y_n - y_1)} \quad (6)$$

3.4 Analysis with Fast Fourier Transform

Actually, the wrinkle evaluation includes three respects: (1) the number of wrinkles in per unit area, (2) the size of wrinkle shape, and (3) height or range of wrinkle shape. Nowadays, the Fast Fourier Transform (FFT), an efficient computational tool in the field of

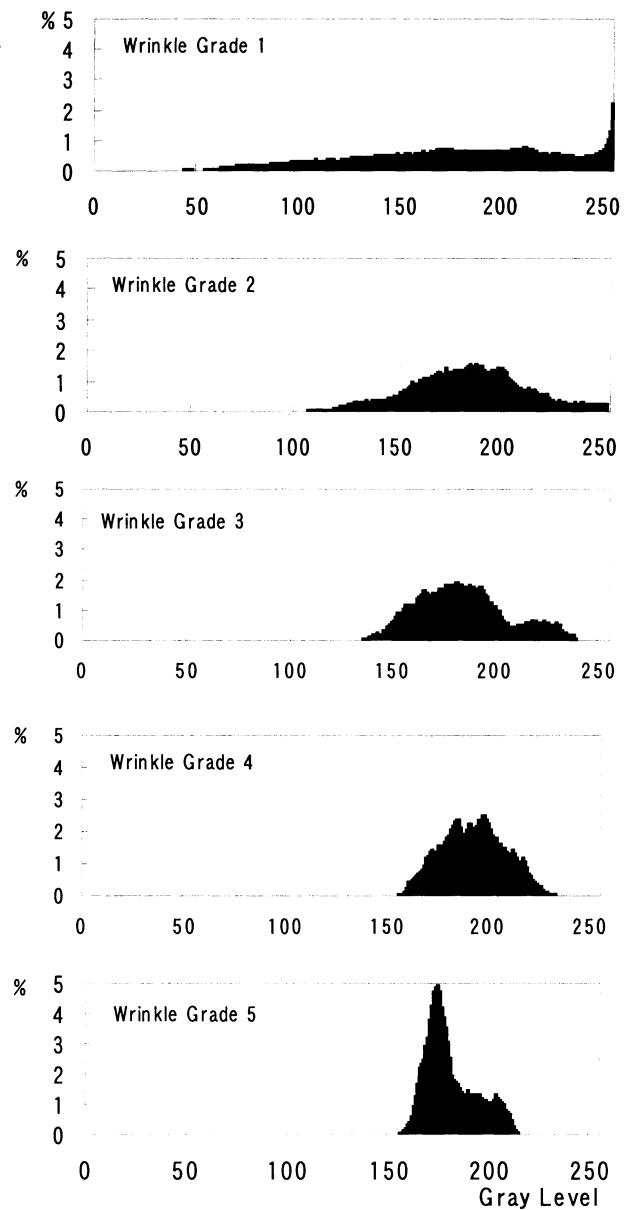


Fig.4 Histogram of distribution of gray level

image processing, has widely been used. We can obtain their spectra of amplitude and frequency to analyze the wrinkle magnitude of surface profile. FFT was first developed by J.W. Cooley and J.W. Tukey from DFT in order to reduce the multiplications, and an algorithm^[10] is given as follows:

$$F(k) = \sum_{n=0}^{N-1} [f_r(n) + jf_i(n)] e^{-j2\pi nk/N} \quad (7)$$

where $F(k)$ is a function of continuous space with N measuring points, $f_r(n)$ and $f_i(n)$ are the amplitudes in terms of real and imaginary transforms, and n and k are the integers with values of 0 to $N-1$. The amplitude spectrum is defined by

$$|f(n)| = \sqrt{f_r^2(n) + f_i^2(n)} \quad (8)$$

Such, amplitudes and frequencies where the peaks appear can quantify the wrinkle appearance.

4. Results and Discussions

Figure 4 shows the histogram of distribution of gray

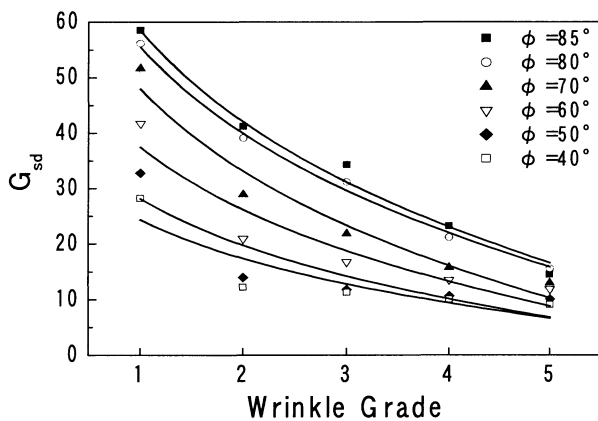


Fig.5 G_{sd} and wrinkle grade

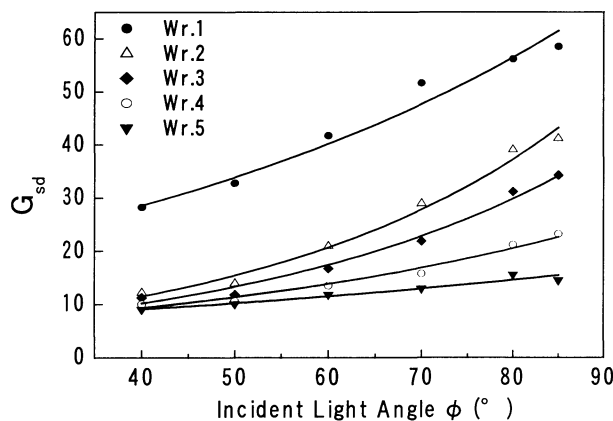


Fig. 6 G_{sd} and incident light angle

level at the incident lighting angle of 70° . There existed not the bi-modal in the histogram of gray level obviously, so it is very difficult to choose a threshold in order to obtain a satisfactory binary image. We feel that it is unfeasible to analyze and measure the wrinkle grade using the method of binary image. The range of distribution of gray level changes with wrinkling. The range is widest from gray level 42 to 255 in wrinkle grade 1, but the range is the narrowest in wrinkle grade 5, whose distribution exists in about gray level 185 mainly.

Figure 5 indicates relationship between G_{sd} and wrinkle grade of replica. Note, the larger G_{sd} is, the higher the wrinkle degree. G_{sd} is affected by the incident light angle as Figure 6 illustrates. With increasing the light angle, G_{sd} also increased. There is a high correlation relationship between G_{sd} and wrinkle grade in every regression curve at 5% significant level, and a very high one between G_{sd} and the incident light angle at 0.1% one.

Because there existed an uneven and a somewhat

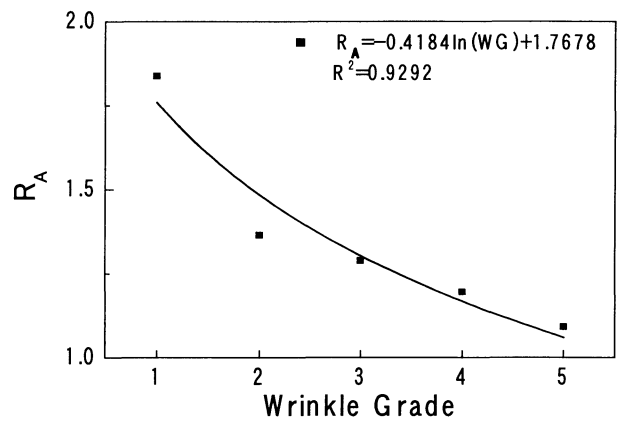


Fig.7 Ratio of surface R_A and wrinkle grade

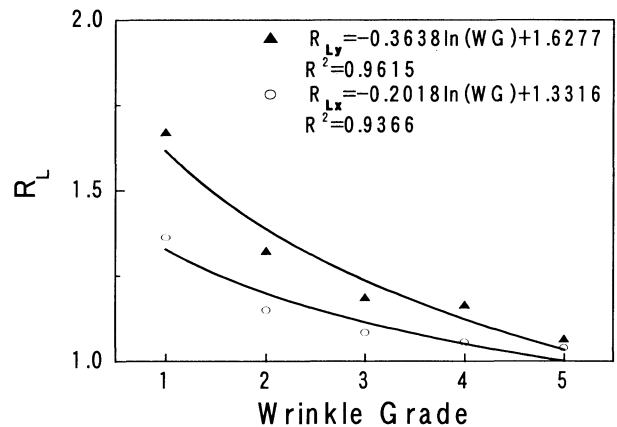


Fig.8 Ratio of length R_{Lx}, R_{Ly} and wrinkle grade

nonlinear behavior of wrinkle grade in the replicas, disparity between wrinkle grade 1 and 2 is too large, but one between wrinkle grade 4 and 5 is too little. It is very difficult to judge the difference between wrinkle grade 4 and 5 when the light angle is less than 50° . The difference between wrinkle grades is clearly reflected when the light angle is or larger than 70° . Following experiments are made in the condition of incident light angle 70° .

The change of ratio of surface area with wrinkling is shown in Figure 7. As shown in Figure 8, when the wrinkle degree is increased, R_{Lx} and R_{Ly} also increase. And others, $R_{Ly} > R_{Lx}$, and the value of $(R_{Ly} - R_{Lx})$ will increase with wrinkling. Only when wrinkle degree is very small, will the value become to near the zero. There is a high correlation relationship between R_A , R_L and wrinkle grade in every regression curve at 1% significant level.

These figures illustrate that all parameters with

wrinkling fall on good logarithmic functions, which have high correlation coefficients with AATCC grades. The trends for wrinkle grades are clear and their results are consistent with the wrinkle grades.

If we exchange the axis of wrinkle grade with the axis of G_{sd} , R_A , or R_L in the above figures, and plot the figures of the relation between them, the relationship corresponds to the Weber-Fechner's law^[11].

Figure 9 indicates their relationship between amplitude and frequency from wrinkle grade 1, 3 and 5, when the profile lines of surface are analyzed with FFT. Note that amplitudes of five grades almost are same and are about zero when $f > 0.1$ (1/ pixel). Amplitudes of five grades are obviously different when $f \leq 0.1$ (1/ pixel). We shall mainly discuss the curve of amplitude and frequency of wrinkle when $f \leq 0.1$ (1/ pixel) and neglect the very small amplitude when $f > 0.1$ (1/ pixel), because it is mainly caused by the sensing noise or intrinsic surface roughness made by the yarn

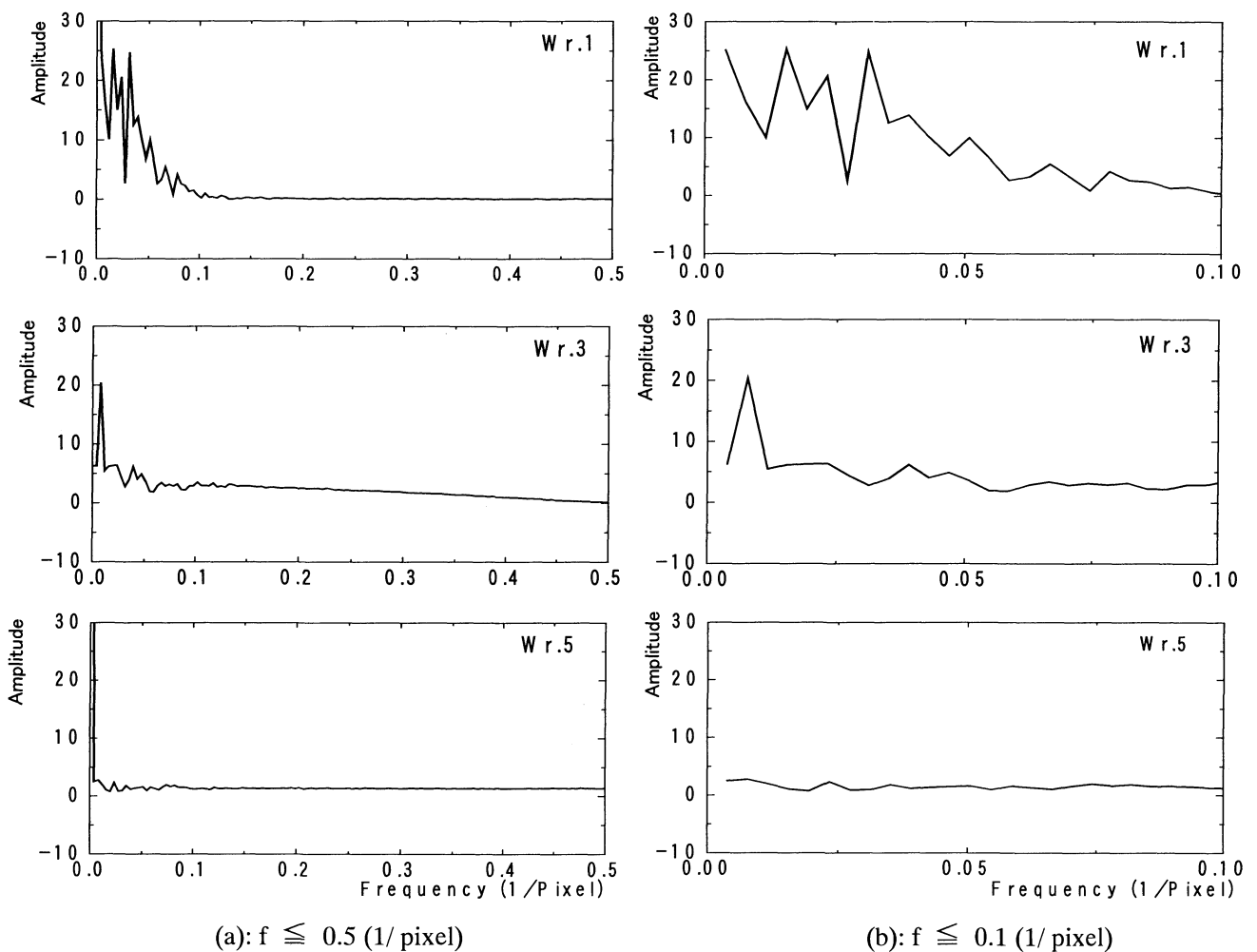


Fig.9 Spectra of profile lines of gray level

interlacing, etc.. Frequency (f) can express the size of wrinkle. The smaller the frequency (f) in which amplitude peak appears is, the larger the size and area of wrinkle is. And amplitude (A) along each frequency reflects the grade difference of gray level, that is, the range and height of wrinkle under this frequency. The difference of five gray levels can clearly be differentiated in the Figure 10. The numerous large peaks of amplitude exist in wrinkle grade 1 when $f < 0.04$, and its value of peak is larger than those of other wrinkle grade. It is said that the wrinkle in grade 1 includes the wrinkle with both shorter and longer wavelength having higher wave height. The numbers and values of peaks in wrinkle grade 2 are less than those in wrinkle grade 1. The value of amplitude of wrinkle grade 3 and 4 in other frequencies is less, except that one larger peak of amplitude appears near about $f = 0.01$. It indicates that there mainly existed wrinkle having large size but small range and depth. It shows there is not entirely any wrinkle or almost smooth in grade 5.

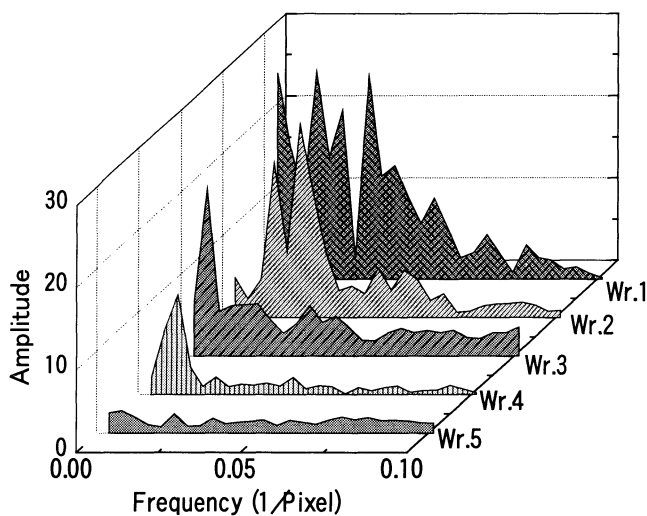


Fig. 10 Spectra of each wrinkle grade

5. Conclusions

The wrinkle grades of standard replicas are measured and analyzed with the image processing system. Following conclusions are obtained:

- (1) All parameters with wrinkling fall on good logarithmic functions, which have high correlation coefficients.
- (2) All parameters used can quantify the wrinkle of replicas.
- (3) There existed an uneven and a somewhat nonlinear behavior of wrinkle grade in the replicas. Disparity between wrinkle grade 1 and 2 is too large, but disparity between wrinkle grade 4 and 5 is too little.
- (4) It is very difficult to judge the difference between wrinkle grade 4 and 5 when the incident light angle is less than 50° . The difference between wrinkle grades is clearly reflected when the light angle is or larger than 70° .
- (5) The spectra of surface profiles can quantify the wrinkle grades with FFT.

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