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Visual Perception of Garment Surface Appearance

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Abstract : This paper concerns with the relationship between the visual perception of the degree of pucker or wrinkles of garment surfaces and the geometrical parameters of surfaces. In this study, four potentially relevant parameters of the surface profile are considered, namely, the variance (σ^2), the cutting frequency (F_c), the effective disparity curvature (D_{ce}) (Defined as the average disparity curvature of the wrinkled surface over the eyeball distance of the observer) and the frequency component of the disparity curvature (D_{cf}). Based on the experiments using garment seams having varying degree of pucker (i.e. the wrinkles along a seam line), it was found that, while the logarithm of each of these four parameters has a strong linear relationship with the visually perceived degree of wrinkles, following the Web-Fetchner Law, the effective disparity curvature (D_{ce}) and the frequency component of the disparity curvature (D_{cf}) appeared to have stronger relationships with the visual perception. This finding is in agreement with the suggestion by Rogers & Cagenello that human visual system may compute the disparity curvature in discriminating curved surfaces. It also suggested an objective method of measuring the degree of surface wrinkles.

Key words : cutting frequency, effective disparity curvature, average disparity curvature, human visual system

Nomenclature

σ^2--Variation of the height of a wrinkle profile.

$z(i,j)$, $z(n_1,n_2)$--Height of the wrinkle profile at the position (i,j).

$\bar{z}$--Average value of $z(i,j)$

$Z(k_1,k_2)$--Frequency domain signal of $z(n_1,n_2)$.

N_1, N_2--Length of the local seam pucker digital signal.

λ--A pre-set ratio of the sum of the amplitudes of the frequency components, the frequency of which are less than the cutting frequency, over the sum of the amplitudes of all frequency components.

F_c--Cutting frequency.

D_c--Disparity Curvature.

D_{ce}--Effective disparity curvature.

D_{cf}--Frequency components of disparity curvature.

D_i--Binocular disparity at point i.

β_i--Vergence angle at point i.

β_{i+1}--Vergence angle at the adjacent point $i+1$.

l--Distance between two eyeballs.

d_i--Distance between the observer and the observing surface.

L--Distance from the observer to reference plane AA' along the Z axes.

z_i, z_{i+1}--Height of the wrinkle profile at point i and the adjacent point $i+1$.

θ_i--Visual angle.

Dg_i--Disparity gradient.

Δ_s--Sampling interval along the X axes and Y axes.

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$G_{i,j}$--Subjective visual grade of ith sample by *j*th observer.

$G''_{i,j}$--Adjusted subjective visual grade of ith sample by *j*th observer.

$\overline{G_j}$--*j*th human observer's mean grade over all samples.

$\overline{G}$-- Mean grade of all samples by all observers.

M-- Number of garment samples.

N-- Number of observers.

The perception of surface profiles is important to tactile sensation and visual appearance. The perceived degree of roughness or wrinkles of a surface is a subjective sensation that depends on a combination of many physical characteristics of the surfaces. This problem has led to many investigations.

On the tactile perception, previous investigations showed that roughness perception is a function of the spatial characteristics (Blake et al., 1997; Meftah et al., 2000; Klatzky et al., 1999), the height, the diameter, and the form or shape of the elements on the surface (Lederman et al., 1972; Sathian et al., 1989; Connor et al., 1990, 1992; Blake et al., 1997).

On the visual perception, considerable researches have been carried out on the detection of characteristics of 3-D surfaces simulated by the optic flow (Anderson et al., 1997; Braunstein et al., 1988; Norman et al., 1992; Cornilleauperes et al., 1992; Perotti et al., 1998; Turner et al., 1995). In general., it was found that the detection performance of corrugated surfaces is affected by the amplitude, corrugation frequency, noise and texture density of the corrugated surface. Comparatively, less work was carried out on the perception of real surfaces. Rogers & Cagenello (1989) conducted many experiments on how human observers perceive and discriminate the curved surfaces and founded that the disparity curvature is an important determinant of the perception of three-dimensional surfaces.

This paper is concerned with the perception of the degree of garment surface appearance in terms of pucker or wrinkles and how it is related to the geometrical parameters of the surfaces. In this study, we considered four potentially relevant parameters of the surface profile, namely, the variance (σ^2), the cutting frequency (F_c), the effective disparity curvature (D_{ce}) and the frequency component of the disparity curvature (D_{cf}). Using experimental results conducted on 25 garment seams having varying degree of pucker (i.e. the wrinkle along the seam line), the relationship between these four parameters and the visually perceived degree of wrinkles is analyzed.

Theoretical Consideration

Consider a wrinkled three-dimensional surface as shown in Figure 1, it is believed that the very high and low frequency components of the surface profile are not perceived by human observers as wrinkles. Instead, the very high frequency components will be perceived as surface texture and the very low frequency components will be

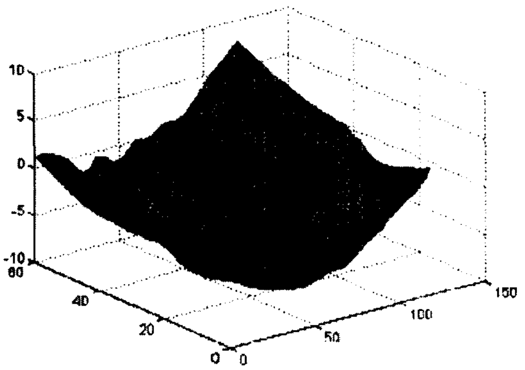


Fig. 1. A wrinkled three-dimensional surface

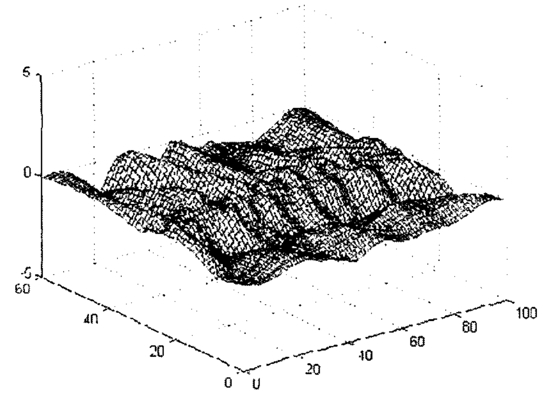


Fig. 2. A wrinkle profile

regarded as surface contours (Fan & Liu, 2000). Therefore, a 2D digital filter may be used to filter out the very high frequency components and very low frequency components so as to subtract the surface profile representing wrinkles. An example of the filtered wrinkle profile is shown in Figure 2.

Variance σ^2 and Cutting Frequency (F_c) of the Wrinkle Profile

It is reasonable to assume that the perceived degree of wrinkles is related to the variation of the height of the wrinkle profile as well as the frequency distribution of the wrinkle profile.

The variation of the amplitude can be measured by the variance σ^2:

$$\sum_{k1=1}^{Fc}\sum_{k2=1}^{Fc}\left|Z(k_1,k_2)\right| = \lambda\cdot\sum_{k1=1}^{N_1/2}\sum_{k2=1}^{N_2/2}\left|Z(k_1,k_2)\right| \tag{1}$$

where $z(i,j)$ is the height of the wrinkle profile at the position (i,j), and $\bar{z}$ is the average value of $z(i,j)$.

The frequency distribution of the wrinkled surface profile can be analyzed by the Fourier Transformation of time domain signal $(Z(k_1,k_2)$, $z(n_1,n_2)$, $n_1 = 1,2,\cdots N_1$; $k_2 = 1,2,\cdots N_2)$ into a frequency domain signal $(Z(k_1,k_2)$, $k_1 = 1,2,\cdots N_1$; $k_2 = 1,2,\cdots N_2)$. The frequency distribution can be measured by the cutting frequency (F_c), which is defined by the following equation:

$$\sum_{k1=1}^{Fc}\sum_{k2=1}^{Fc}\left|Z(k_1,k_2)\right| = \lambda\cdot\sum_{k1=1}^{N_1/2}\sum_{k2=1}^{N_2/2}\left|Z(k_1,k_2)\right| \tag{2}$$

where $0<\lambda<1$, is a pre-set ratio of the sum of the amplitudes of the frequency components, the frequency of which are less than the cutting frequency, over the sum of the amplitudes of all frequency components. A greater F_c means more high frequency components in the wrinkled surface profile.

Effective disparity Curvature(D_{ce}) and Its Frequency Components (D_{cf})

It was proposed by Rogers and Cagenello (1989) that disparity curvature is an important determinant of the perception of three-dimensional surfaces. It was therefore postulated that the disparity curvature and its frequency components would relate to the perception of surface wrinkles.

The disparity curvature can be calculated from the wrinkle profile, i.e.

$$D_c = \frac{l}{(I-1)(J-3)} \sum_{i=1}^{I}\sum_{j=1}^{J-2}\left|((z(i,j+1)-z(i,j))-((z(i,j+2)-z(i,j+1))\right| \tag{3}$$

where, l is the distance between the eyeballs. The mathematical derivations of Equation (3) are described in the Appendix A. As l is a constant, we need only to be concerned with ($\frac{Dc}{l}$). We therefore define ($\frac{Dc}{l}$) as the effective disparity curvature (D_{ce}):

$$D_{ce} = \frac{Dc}{l} = \frac{1}{(I-1)(J-3)} \sum_{i=1}^{I}\sum_{j=1}^{J-2}\left|((z(i,j+1)-z(i,j))-((z(i,j+2)-z(i,j+1))\right| \tag{4}$$

The frequency components (D_{cf}) of disparity curvature can be calculated from the frequency domain signal of the disparity curvature, i.e.:

$$D_{cf} = \sum_{k_1=1}^{I/2}\sum_{k_2=1}^{(J-2)/2}\left|Dce(k_1,k_2)\right| \tag{5}$$

where, $Dce(k_1,k_2)$ is the frequency domain signal obtained by Fourier Transform corresponding to the time domain signal $Dce(i,j)$.

Experimental

Samples and Subjective Assessment

In order to examine how these four parameters relate to the perceived degree of wrinkles, 25 garment seams (i.e. stitched joint connecting two fabric panels) having varying degree of pucker (or wrinkle) were made. The variation in seam pucker was achieved by varying the stitch density and top and bottom thread tension of the sewing machine during sewing. Higher thread tension and lower stitch density tended to create severer wrinkles. The details of the samples are shown in table 1.

The seam samples were visually assessed in terms of the degree of wrinkles according to the AATCC standard by 13 human observers, all having at least 5 years experience in garment technology, in Grade 1, 2, 3, 4, and 5. Grade 1 means worsted pucker or wrinkle and Grade 5 means no wrinkle at all.

AATCC standards are standards of American Association Of Textile Chemists And Colourists. Standard AATCC-88B provides two sets of photographic seam smoothness replicas for single stitched and double stitched seams, respectively, as shown in appendix I.

Garment seam samples were pinned on a dress-making mannequin for visual assessment. The AATCC photographic standards were positioned in the same visual level and under the same light condition as those for the garment seams. The light source was incident from above casting a shadow over the garment seams to highlight the wrinkles. The observers stood straight and 100cm in front of the garment seam specimens. The observers were instructed to assign numerical grades to the seams in terms of the degree of wrinkles in accordance with the photographic standards.

Considering the possible bias of any single observer, we adjusted the subjective visual grades by following:

$$G^*_{i,j} = \frac{G_{i,j}}{\overline{G}_j}\overline{G} \tag{6}$$

where, *i*—*i*th sample; *j*—*j*th human observer;

$G_{i,j}$--Subjective visual grade of *i*th sample by *j*th observer;

Table 1. Samples in experiment

Sample code		Thread tension (kg)				
		Top 0.16/ under0.07	Top 0.14/ under0.06	Top 0.12/ under0.05	Top 0.09/ under0.03	Top 0.07/ under0.02
Stitch density	7/cm	St11	St21	St31	St41	St51
	6/cm	St12	St22	St32	St42	St52
	5/cm	St13	St23	St33	St43	St53
	4/cm	St14	St24	St34	St44	St54
	3/cm	St15	St25	St35	St45	St55

Table 2. The Details and Mean Subjective Grade of Samples

Sample Code	Conditions for sample preparation			σ^2
	Stitch density (cm-1)	Top thread tension (kgf)	Bottom thread tension (kgf)	
st11	7	0.16	0.07	2.34
st12	6	0.16	0.07	2.09
st13	5	0.16	0.07	2.64
st14	4	0.16	0.07	2.96
st15	3	0.16	0.07	2.74
st21	7	0.14	0.06	2.19
st22	6	0.14	0.06	2.84
st23	5	0.14	0.06	3.28
st24	4	0.14	0.06	3.19
st25	3	0.14	0.06	2.6
st31	7	0.12	0.05	3.29
st32	6	0.12	0.05	3.51
st33	5	0.12	0.05	3.37
st34	4	0.12	0.05	3.83
st35	3	0.12	0.05	3.07
st41	7	0.09	0.03	3.11
st42	6	0.09	0.03	3.55
st43	5	0.09	0.03	3.37
st44	4	0.09	0.03	3.38
st45	3	0.09	0.03	3.68
st51	7	0.07	0.02	4.33
st52	6	0.07	0.02	4.7
st53	5	0.07	0.02	4.66
st54	4	0.07	0.02	4.47
st55	3	0.07	0.02	4.87

$G^{*}_{i,j}$--Adjusted subjective visual grade of ith sample by jth observer;

$\overline{G_j}$ --*j*th human observer's mean grade over all samples, $\overline{G_j}=\frac{1}{M}\sum_{i=1}^{M}G_{i,j}$, (M is number of samples M=25);

$\overline{G}$ -- the mean grade of all samples by all observers, $\overline{G}=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}G_{i,j}$, (N is number of observers, N=13).

From the adjusted grades, we then calculate the mean subjective grade of each sample $\overline{G_i}$ by:

$$\overline{G_i}=\frac{1}{N}\sum_{j=1}^{N}G^{*}_{i,j} \tag{7}$$

The details and mean subjective grades are listed in Table 2.

Procedure for Deriving the Objective Parameters of the Wrinkled Surface

The garment seams pinned on the dress-making mannequin were firstly scanned using a 3-D laser scanner to obtain point clouds of the surfaces. From the point clouds, meshed surfaces were then constructed using a commercial software (i.e. SURFACER). The meshed surfaces were then filtered using a 2-D digital band-pass filter to remove very high frequency component representing the fabric texture and very low frequency components which arises from the surface contour (Fan and Liu, 2000) to obtain the wrinkle profiles (See Figure 2).

From the wrinkle profiles, the four potentially relevant parameters, namely, the variance (σ^2), the cutting frequency (F_c), the effective disparity curvature (D_{ce}) and the frequency component of the disparity curvature (D_{cf}) were derived based on Equation (1), (2), (4) and (5), respectively. The cutting frequency (F_c) were obtained at λ=0.25 as preliminary computation showed that F_c at λ=0.25 had the strongest relationship with the subjective wrinkle grade.

Result Analysis and Discussion

Correlation between wrinkle perception and each of the four parameters

The four parameters, σ^2, F_c, D_{ce}, and D_{cf} are individually correlated with the mean subjective grades of the wrinkled surfaces. The correlations are shown in Figures 3-6. As can be seen, the logarithm of each of the four parameters has strong linear relationship with the subjective grade, following the Web-Fechner Law.

From Figure 3, we can see greater values of log (σ^2) will lead to lower subjective grade. This is reasonable as more variations in the height of the surface profile should give more sever wrinkle perception.

The decrease of subjective grade (or increase of wrinkle severity) with the increase of cutting frequency (F_c) shown in Figure 4 means more high frequency components results in greater severity of wrinkle perception.

As shown in Figure 5, the logarithm of effective

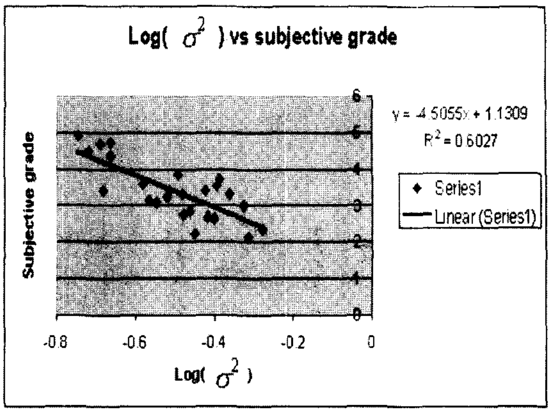


Fig. 3. Linear regression analysis of log(σ^2) vs the subjective grade

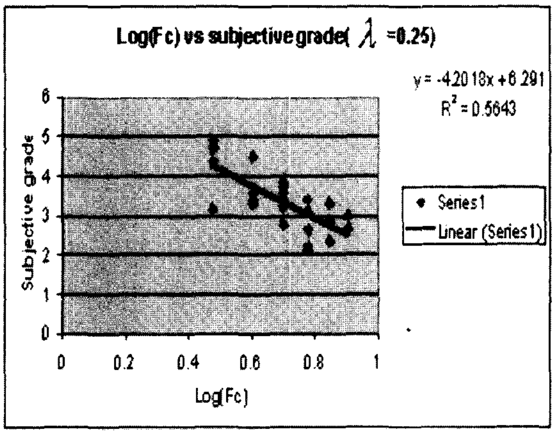


Fig. 4. Linear regression analysis of log(F_c) vs the subjective grade

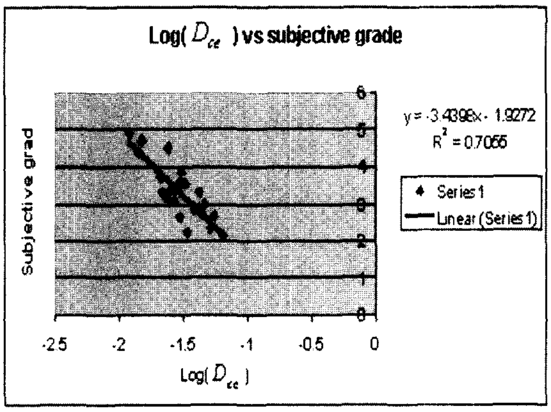


Fig. 5. Linear regression analysis of log(D_{ce}) vs the subjective grade

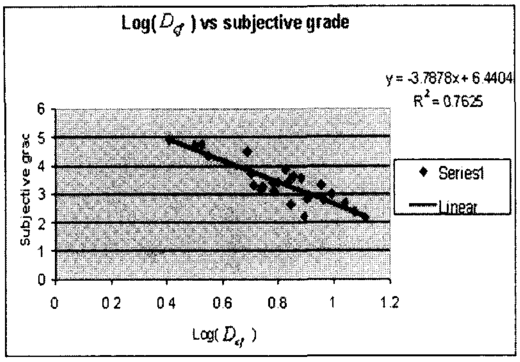


Fig. 6. Linear regression analysis of log(D_{cf}) vs subjective grade

disparity curvature log(D_{ce}) has a stronger linear relationship with the subjective wrinkle grade than that of log(σ^2) and log(F_c), suggesting that the effective disparity curvature is a better determinant of wrinkle perception. A greater D_{ce} means sharper curvature of the surface, hence understandably greater severity of wrinkle perception.

From Figure 6, the logarithm of the frequency component of disparity curvature [log(D_{cf})] has the strongest linear relationship with the wrinkle perception. It means that human visual system may be able to evaluate the frequency of the change of disparity curvature of a wrinkles surface. The higher the frequency, the greater the wrinkle severity.

Interrelationship Between the Four Measures of Wrinkles

Table 3 lists the inter-correlation between any two of the four measures of wrinkles. As can be seen, the logarithm of effective disparity curvature log(D_{ce}) is highly related to the logarithm of the frequency component of disparity curvature [log (D_{cf})], indicating that these two parameters effectively measure the same thing. However, the inter-correlation between other parameters, i.e. between log(σ^2), log(F_c) and log(D_{ce}) or between log(σ^2), log(F_c) and log(D_{cf}) are much less with the value of squared correlation coefficient ranging from 0.65 to 0.74. This indicates that the variance of the wrinkle profile, the distribution of the frequency of the wrinkle profile and the effective disparity curvature are not the same thing, although related.

Conclusions

In this paper, we have analyzed the relationship between the visual perception of the degree of garment pucker or wrinkles and four relevant geometrical parameters of surfaces, namely, the variance (σ^2), the cutting frequency (F_c), the effective disparity curvature (D_{ce}) (Defined as the average disparity curvature of the wrinkled surface over the eyeball distance of the observer) and the frequency component of the disparity curvature (D_{cf}). Based on the experiments using garment seams having varying degree of pucker (i.e. the wrinkles along a seam line), it was found that, the

Table 3. Interrelation Between Four Measures of Wrinkles

Squared correlation Coefficient (R^2)	Log(σ^2)	Log(F_c)	Log(D_{ce})	Log(D_{cf})
Log(σ^2)	1	0.6538	0.6998	0.7418
Log(F_c)	0.6538	1	0.6998	0.6996
Log(D_{ce})	0.6998	0.6998	1	0.9739
Log(D_{cf})	0.7418	0.6996	0.9739	1

logarithm of each of these four parameters has a strong linear relationship with the visually perceived degree of wrinkles, following the Web-Fetchner Law. The logarithm of effective disparity curvature log(D_{ce}) and the logarithm of the frequency component of disparity curvature [log(D_{cf})] are highly related and tend to provide better measures of the degree of wrinkles than the variance of the wrinkle profile and its frequency distribution. This may suggest that human visual system are sensitive to the disparity curvature of a wrinkles surface.

Appendix A

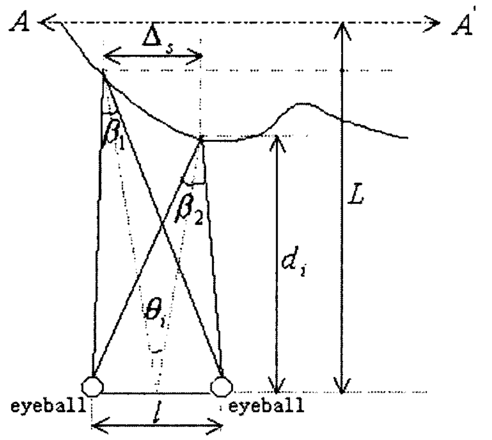


Fig. a. Definition of the disparity curvature (A-A is reference plane)

The disparity curvature was defined as the second derivatives of the binocular disparity (D_i). The binocular disparity (D_i) between two points in space is defined as the difference in the vergence angles needed to fixate each of the two points (See Figure a), i.e.:

$$D_i = \beta_i - \beta_{i+1} \tag{a1}$$

where, β_i is the vergence angle at point *i* and β_{i+1} is the vergence angle at the adjacent point $i+1$. As the distance (*l*) between two eyeballs is much smaller than the distance between the observer and the observing surface (D_i), β_i and β_{i+1} can be approximately calculated by:

$$\beta_i = \frac{l}{d_i} = \frac{l}{L - z_i} \tag{a2}$$

$$\beta_{i+1} = \frac{l}{d_{i+1}} = \frac{l}{L - z_{i+1}} \tag{a3}$$

where, *L* is the distance from the observer to reference plane AA' along the *Z* axes. z_i and z_{i+1} are the height of the wrinkle profile at point *i* and the adjacent point $i+1$ against the reference plane AA'.

The rate of the change of binocular disparity over the visual angle (θ_i) is defined as the disparity gradient (Dg_i), i.e.:

$$Dg_i = D_i / \theta_i = (\beta_i - \beta_{i+1}) / \theta_i \tag{a4}$$

The visual angle (θ_i) can be approximated by:

$$\theta_i = \frac{\Delta_s}{d_i} = \frac{\Delta_s}{L - z_i} \tag{a5}$$

where, Δ_s is the sampling interval along the X axes and Y axes. From Equation (a2), (a3), (a4) and (7), we can therefore have:

$$\begin{aligned} Dg_i &= \left(\frac{l}{L - z_i} - \frac{l}{L - z_{i+1}}\right) / \left(\frac{\Delta_s}{L - z_i}\right) \\ &= \frac{(L - z_{i+1}) - (L - z_i)}{(L - z_i)(L - z_{i+1})} \cdot \frac{L - z_i}{\Delta_s} \cdot l = \frac{z_{i+1} - z_i}{L - z_{i+1}} \cdot \frac{l}{\Delta_s} \end{aligned} \tag{a6}$$

Disparity curvature (Dc_i) is defined as the rate of change of disparity gradient (Dg_i) over the visual angle (θ_i), i.e.:

$$\begin{aligned} Dc_i &= (Dg_i - Dg_{i+1}) / \theta_i \\ &= \left(\frac{z_{i+1} - z_i}{L - z_{i+1}} \cdot \frac{l}{\Delta_s} - \frac{z_{i+2} - z_{i+1}}{L - z_{i+2}} \cdot \frac{l}{\Delta_s}\right) \cdot \frac{L - z_i}{\Delta_s} \\ &= \left(\frac{z_{i+1} - z_i}{L - z_{i+1}} - \frac{z_{i+2} - z_{i+1}}{L - z_{i+2}}\right) \cdot (L - z_i) \cdot \frac{l}{\Delta_s^2} \end{aligned} \tag{a7}$$

Since $L \gg z_i$, $L \gg z_{i+1}$, $L \gg z_{i+2}$, we can obtain:

$$Dc_i = ((z_{i+1} - z_i) - (z_{i+2} - z_{i+1})) \cdot \frac{l}{\Delta_s^2} \tag{a8}$$

If the sampling interval is set to be 1 unit, viz.

$\Delta_s = 1$, we have

$$Dc_i = ((z_{i+1} - z_i) - (z_{i+2} - z_{i+1})) \cdot l \tag{a9}$$

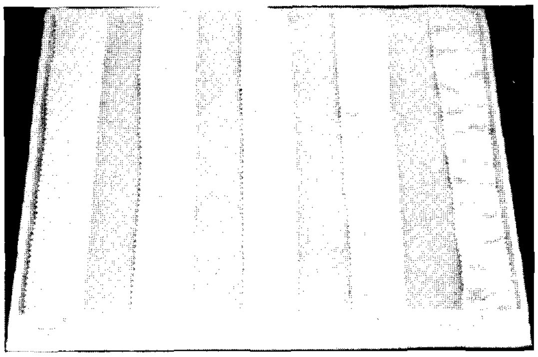
For a wrinkled surface area under consideration, the mean disparity curvature (Dc) therefore is:

$$Dc = \frac{1}{(I-1)(J-3)} \sum_{i=1}^{I} \sum_{j=1}^{J-2} \left| Dc(i,j) \right| \tag{a10}$$

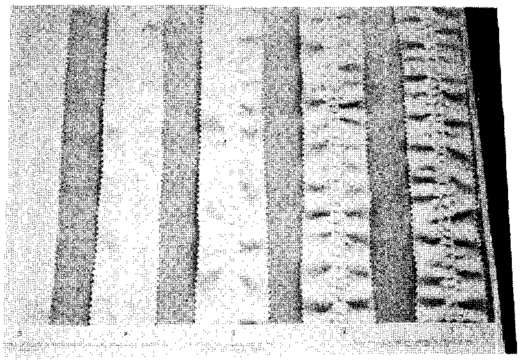
As the distance between the eyeballs (l) is a constant, we need only to be concerned with ($\frac{Dc}{l}$), which we define as the effective disparity curvature (D_{ce}):

$$D_{ce} = \frac{Dc}{l} = \frac{1}{(I-1)(J-3)} \sum_{i=1}^{I} \sum_{j=1}^{J-2} \left| ((z(i,j+1) - z(i,j)) - ((z(i,j+2) - z(i,j+1)) \right| \tag{a11}$$

Appendix B AATCC Photographic Standards



AATCC 88B Seam Smoothness Photo Standard for single stitched seams



AATCC 88B Seam Smoothness Photo Standard for double stitched seams

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