A New Approach to the Objective Evaluation of Fabric Handle from Mechanical Properties

Part I: Objective Measure for Total Handle

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ABSTRACT

The existing problems of the current methods for fabric handle evaluation are analyzed and as an alternative, a new measure, the weighted Euclidean distance (WD) value, of total handle is proposed. Using this method, one can specify the preferences of fabric handle. The whole process for deriving and calculating this measure is also introduced. Through illustration and comparison with Kawabata's THV value, the advantages and applicability of the WD value to fabric handle evaluation are demonstrated.

Quantitative specification of fabric handle from fabric mechanical property data is the key to objective assessment of fabric handle. More than fifty years have passed since the earliest efforts on this problem were described by Peirce [10]. Several studies have been undertaken in this area [4], notably Kawabata's method of the Japanese HESC in the 1970s.

In this paper, we present a new approach with a mathematical method 'to indirectly determine the weights of multivariables concerned with fabric handle, and we obtain a weighted Euclidean distance (WD value) and some other objective measures to evaluate total handle and primary handle (as in Kawabata's system), respectively. We also address the problem of rea-

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sonably grading fabric handle as an additional proposal. The study is divided into three parts: the first paper concentrates on the problem of total fabric handle

evaluation, and the problems of primary fabric handle evaluation and handle grading are the subjects of the second and the third papers, respectively.

Nature of Fabric Handle and Problems of Evaluation

HANDLE SUBJECTIVITY AND RELIABILITY

The importance of fabric handle to the appreciation and saleability of fabric products is undisputed. Since fabric handle is based on people's subjective preferences, obviously it can mean different things to different people. For different markets, different products, and consumers with different backgrounds, the preferences for certain fabric types are diverse and, in extreme cases, even opposite. The results given in Table I, which is adopted from Mahar and Postle's study [8] of an international survey for sensory assessment of fabric handle, are an interesting example. In this survey, which was coordinated by Kawabata *et al.*, an extensive range of fabrics was assessed for fabric handle by panels of expert judges drawn from the textile and clothing industries of Japan, Australia, New Zealand, India, and the United States. To show the level of agreement between judges within and between each of the countries surveyed, the mean correlation coefficients in both cases were computed.

The results in the table reveal that for the same fabrics, acceptability varies with judges from different countries. Especially for summer weight fabrics, the Japanese panel of judges showed a marked disagreement or even opposite preferences, indicated by the negative correlations. This kind of diversity is a psychological fact, but until psychology can derive a strict formulation for the fundamental relationship between physical stimuli and human sense perception, it is impossible for the textile scientists to thoroughly solve the problem of evaluating fabric handle using a purely analytical method.

Despite this problem, the assessment of fabric handle is still **meaningful, partly because it can satisfy at least** some of the requirements of practical textile production and trading, and partly because of the reliability of the fabric handle phenomenon within specific ranges (*i.e.*, for certain kinds of people, products, and markets). To demonstrate this, another result, correlations within groups, is provided from the same source (Table II).

TABLE II. Within-group correlation coefficients of total handle.

National judging panel	Winter fabrics	Summer fabrics
8 Japanese	0.85	0.79
8 Australian	0.89	0.74
8 New Zealand	0.70	0.66
8 Indian	0.82	0.15
8 United States	0.80	0.72
8 Consumers	0.63	0.61

The high values of the within-group correlation coefficients indicate that these expert judges definitely agree, within each national group, about the handle rating of these fabrics, and even the untrained consumer judges still show reasonable agreement between themselves. It is just this fact of the local reliability or consistency of fabric handle preference that provides the meaning and possibility of fabric handle evaluation.

PROBLEMS OF EXISTING APPROACHES

The traditional method for assessing fabric handle is the tactile sensory technique, which is probably the most reasonable. As Brand [2] stated, "The aesthetic concepts [of fabrics] are basically people's preferences and should be evaluated subjectively by people." This apparent common-sense approach immediately raises difficulties, however, such as finding the most appropriate judges-experts or untrained consumers? There is difficulty with the communication between judges, the low assessment sensitivity, and above all the timeconsurning nature of the whole assessment procedure. The conclusion is that a reliable subjective evaluation of fabric handle is possible, but obviously the method does not facilitate rapid development of textile products.

TABLE I. Correlation coefficients between pairs of international judging panels.

	Japan	Australia	New Zealand	India	U.S.A.
Japan	`""-'--	0.85		0.76 0.82	0.80 for
Australia	for -0.34		-_~ 0.86 -"'-`----	0.91	0.87 winter
New Zealand	-0.30	0.82		0.83	0.83 fabrics
India	summer _0,41	0.78		0.76	0.86
U.S.A.	fabrics _0.33	0.81		0.74 0.76	'-

Another conspicuous method is Kawabata's system, which consists of a set of instruments known as the KES-F or FB system for measuring fabric mechanical properties and the equations for handle value calculation. This system raises research to a new level, but there are still some problems with it. The system uses multivariate regression to relate the subjective assessment results completed by the Japanese experts to the objectively measured data on the KES-F instruments and to formulate the equations for handle value calculation. Because the system is based on the preferences of Japanese judges, the unsuitability of the results to markets other than Japan [1] is inevitable, owing to the background-related nature of tactile sensory assessment.

A similar procedure could, of course, be used to formulate equations for handle value calculations relating to other markets and other products. The tremendous work involved discourages application and makes a comprehensively applicable system impractical. The remaining problem in this system is a mathematical one: the validity of multivariate regression analysis is often severely influenced by so-called colinearity of the data, which appears to exist between the mechanical parameters measured on the KES instrument [9].

DIFFICULTIES OF OBJECTIVE EVALUATION

The main reason for proposing an objective evaluation of fabric handle is that tactile sensory assessment cannot be adapted to the textile industry. The high sensitivity of physical instruments to textile properties is an additional reason. The design and precise prediction of fabric handle depend on objective and quantitative specifications. This is the main justification for the research into fabric handle evaluation.

The identification of quantitative and objective measures that most closely represent the phenomenon of fabric handle preferences (which, however, are themselves subjective and liable to local or individual variations) is the most desirable target and at the same time presents the greatest difficulty in objective evaluation of fabric handle.

It is widely recognized that the stimuli leading to the psychological responses of fabric handle are entirely determined by the physical and mechanical properties of fabrics. This is one of the bases for the possibility of fabric handle objective evaluation, and another is the fact of local reliability or consistency of psychological response of fabric handle preference in fixed conditions.

In some earlier papers, the definitions for fabric handle were ambiguous or lopsided. In Kawabata's system [6], however, fabric handle was divided into three levels—total hand → primary hand → basic mechanical properties—which clarified the situation. In this paper, we will therefore use similar definitions to divide fabric handle into three levels.

In the first part of the paper, we attempt to derive an objective and more reasonable gauge to measure the total handle of fabrics. The necessity of such a comprehensive index is mainly because of the practical need for convenience of communication. Moreover, the procedure of tactile sensory assessment itself is also a somewhat subconscious transformation and calculation—from the various physical stimuli to a final assessment.

Objective Measure for Total Hand Specification

CONCEPT OF EUCLIDEAN DISTANCE

Distance is a useful concept to show the difference between samples. The definition of general Euclidean distance in mathematics is as follows: If X and Y are two points in an n dimensional space, where

$$X = (X_1, X_2, \cdots X_n) ,$$
$$Y = (Y_1, Y_2, \cdots Y_n) . \qquad (1)$$

then the general Euclidean distance D between them is

$$D(X, Y) = \left(\sum_{k=1}^{n} (X_k - Y_k)^2 \right)^{1/2} . \qquad (2)$$

Similarly, if each of two fabric samples is described by a vector X, and n components of which are mechanical properties, i.e.,

$$X_1 = (X_{11}, X_{12}, \cdots X_{1n})$$
$$X_2 = (X_{21}, X_{22}, \cdots X_{2n}) ,$$

the expression of $D(X_1, X_2)$ then becomes

$$D(X_1, X_2) = \left(\sum_{k=1}^{n} (X_{1k} - X_{2k})^2 \right)^{1/2} . \qquad (4)$$

It is apparent that the value of $D(X_1, X_2)$ can be used to indicate differences in the mechanical properties of these two fabrics, and therefore in total fabric handle as well, since the latter depends on the former. Furthermore, if a standard sample k is chosen as the origin of the coordinates and correspondingly described by a vector X_k, the distances of other fabrics to X_k are then stable and comparable and can be used as an objective measure of total handle.

DETERMINING WEIGHTS OF VARIABLES

It is often meaningless to use initial variables because of their differences in nature and units, especially in their importance to the final result. It is also possible that fabrics with identical values of D as defined above possess different characteristics of total handle. To overcome this fault, it is necessary to determine the weight of each variable and define a weighted distance.

By means of the Karhunen-Loeve (K-L) orthonormal expansion theorem [5] of the statistical pattern recognition technique, a random vector X = (XI, Xz, • • • Xn), with mean vector E(X) = E and covariance matrix Var (X) = V, can be replaced by an orthonormal vector Y through a matrix transformation

$$Y = XR \qquad (5)$$

without any information loss, where

$$Y = (YmYz, \cdots YP),\ psn$$

$$R = (R_{,}, Rz, \cdots RP) . \qquad (6)$$

R,, Rz, • • • *RP* are the p eigenvectors corresponding to the p prior eigenvalues of the covariance matrix V of X. The new vector Y, called the feature vector of the original vector X, has the following interesting properties: (a) In general, the dimensions of Y are less than those of X, that is, p < n. (b) The components of Y are all uncorrelated with each other, since Y is orthonormal. This is very useful for determining the. weight of each component and for further processing. (c) The relative importance of each component Y; (i = 1, 2, • • • p) in expressing the vector X is represented by the corresponding eigenvalue C; associated with *R;*. So the ratio

$$C;/ \sum_{k-I} Ck = C;/tr\ V , \qquad (7)$$

where $tr\ V = \sum_{k-1}^{n} Ck$ is the trace of the covariance matrix V, can be defined as the weight of the component Y;.

WEIGHTED EUCLIDEAN DISTANCE AS AN OBJECTIVE MEASURE

For the fabric samples X1, Xz above, after the transformation, the corresponding feature vectors are

$$Yi = (Ym\ Yiz, \cdots YAP)$$

$$Yz = (Y2\ I, Yzz, \cdots YzP)$$

respectively. The definition of the weighted Euclidean distance between them is

$$WD = (\sim \sum_{r-i}^{P} (Wr(yo - yzr)z))1iz \sim \qquad (9)$$

where *W; _ (C;/trV)'1z is* the weight of ith component of Y. Generally, taking fabric sample k as the standard sample for the calculation, Equation 9 becomes

$$WDk = (\sum^{P} (Wi(Yu - yk,)z))Il . \qquad (l0)$$

We can expect that such a revised distance describes the difference in fabric handle more reasonably. The larger the value of *WDk,* the greater the difference in total handle between a fabric and the standard sample.

Because of the subjective and background-related nature of fabric handle, it seems hard to imagine that the various handle preferences can be specified by a single universal index. In the general case, therefore, the value of *WD is* just a guage objectively representing fabric handle difference rather than preference. For a local case, however, if a specific handle preference (that is, a standard sample as the origin of *WD* value computation) is given by either consumers and buyers or according to the experiences of manufacturers themselves (in practice, it is often possible), the WD values can reflect the degree of fabric handle excellence corresponding to this given case. The higher the WD value, the further away from the standard sample, and the worse the handle of this fabric, given that the standard sample provides a known standard of the most excellent handle in this specific case.

Even in the case where a standard sample cannot be provided, we can designate the real origin (o point), that is, a non-existent sample as the computation standard. Fabrics with identical values of WD, will still be the same in handle, but the WD, value can no longer evaluate the handle preference. In fact, even for the tactile sensory assessment method, it presumes the existence of the preference standard in the judge's conscious or subconscious mind. Indeed in the absence of such an existing preference, the whole concept of handle evaluation becomes meaningless.

CALCULATION AND EXAMPLE

After discarding the abnormal samples, we chose 48 samples to compose the sample set. All are medium thickness suiting fabrics and the characteristics are as follows:

	Max.	Min.	Mean	Var.
Weight, g/cm2	31.48	22.48	26.19	2.32
Thickness, mm	0.92	0.61	0.74	0.08

Data are measured using the KES-FB instrument system, with 16 variables for each sample. The details of these parameters refer to the introduction of the KES-FB instrument system [6]. The original matrix is formed as

$$X = (X_{ij}'), \quad i = 1, 2, \cdots m \qquad j=1,2, \cdots n , \tag{11}$$

where m = 48 is the number of samples and $n = 16$ is the dimension of the variables.

The method is sensitive to the units in which the original variables are measured. If the units of measurement are not uniform, the results may not be meaningful. Consequently before further calculation, the original matrix X must be standardized, i.e.,

$$X_{ij} = (X_{ij}' - E_j)/V_j , \tag{12}$$

where X_{ij}' and X_{ij} are the components of matrix X before and after the process, and E_j and V_j are the values of mean and variance of the jth variable. Then the covariance matrix V of X is calculated as

$$V = (V_{il}), \quad i, l = 1, 2, \ldots n , \tag{13}$$

By means of the Jacobi algorithm, the n eigenvalues C_i and the eigenvectors R_i $(i = 1, 2, \cdots n)$ of the covariance matrix V are easily obtained.

Ranking C_i in the sequence of their values,

$$C_1 \geq C_2 \geq \cdots \geq C_n , \tag{14}$$

and selecting p prior values $C_1, C_2, \cdots C_p$ (p < n) (see Table III) to satisfy the condition (8),

$$\sum_{i=1}^{p} C_i/\mathrm{tr}V \geq 0.85 \tag{15}$$

the transformation matrix R in Equation 5 is then composed of the p = 8 eigenvectors R_i (i = 1, 2, p) corresponding to the prior p eigenvalues and, after the transformation, the feature matrix Y of the original matrix X is derived with the weight W_i of each component Y_i.

According to Equation 10 and with the feature matrix Y as well as its weight of the fabrics, the WD values of all samples are calculated and shown in Table IV, where THV = Kawabata's total hand value, which is provided for the purpose of comparison; WD = the WD value proposed in this paper; TR = the preference rank given by the THV values: the larger the value, the better in total handle (sample no. 32 with the largest THV value is therefore considered the best, so this

TABLE IV. Forty-eight samples, calculated results.

No.	THV	WD	TR	WR
1	4.352	1.424	5	11
2	2.744	2.877	37	42
3	3.898	2.269	18	31
4	2.924	2.389	31	33
5	2.738	2.598	38	39
6	3.639	1.595	22	1S
7	2.961	1.721	29	17
8	4.427	2.107	2	24
9	4.180	2.509	10	37
10	3.708	1.300	20	10
11	3.786	2.120	19	25
12	3.681	1.618	21	16
13	1.177	2.022	48	21
14	2.751	2.139	36	26
1S	3.199	2.207	25	28
16	2.875	1.935	33	30
17	2.916	2.415	32	35
18	4.3638	2.053	4	23
19	1.622	3.798	46	47
20	3.931	1.278	16	8
21	3.943	1.588	15	14
22	3.568	1.832	23	18
23	2.831	2.557	34	38
24	2.797	2.212	35	29
25	2.0076	3.356	44	45
26	2.376	2.687	41	41
27	3.455	2.243	24	30
28	3.088	2.023	28	22
29	3.159	2.204	27	27
30	3.920	1.548	17	13
31	4.106	1.007	17	13
32	4.557	0	1	1
33	4.135	1.110	12	7
34	4.414	0.607	3	2
35	4.246	0.836	8	3
36	4.181	1.534	9	12
37	4.026	0.992	14	5
38 .	4.316	0.869	6	4
39	4.172	1.289	11	9
40	4.254	1.882	7	19
41	3.169	2.498	26	36
42	1.393	4.060	47	48
43	1.850	3.743	45	46
44	2.656	2.613	40	40
45	2.945	2.342	30	32
46	2.548	2.931	42	44
47	2.138	2.397	43	34
48	2.729	2.901	39	43

TABLE III. The prior eight eigenvalues and the weights W_i.

	1	2	3	4	5	6	7	8
C_i	4.032	3.120	2304	1.440	1.200	0.816	0.672	0.656
W_i	0.252	0.195	0.144	0.090	0.075	0.051	0.042	0.041
$\sum W_i$	0.252	0.447	0.591	0.681	0.756	0.807	0.849	0.890

sample is designated as the standard sample for calculating IUD values); and *WR* = the preference rank according to WD values.

We must point out that the preference rank TR given by the THV value should represent the subjective preference of the Japanese (at least those of the experts who participated in the fabric hand assessment for Kawabata's system) because of the local consistency of subjective fabric handle. On the other hand, this may be different from that of others outside Japan due to the background-related nature of handle. So when sample no. *32,* which is the best in terms of Japanese preference, is chosen to be the standard sample for WD values, the evaluation results *WR* should agree with that of *TR.*

COINCIDENCE TEST FOR WR VERSUS *TR* RANKS

Using the Friedman rank correlation test [31, the statistic *F* has a value of *8.299.* The critical value of *F* at the 0.01 level for the coincidence test is

$$Fa<2.11 \,. \qquad (16)$$

Since

$$F = 8.299 > Fa \,, \qquad (17;$$

both ranks are significantly consistent.

The example here is only one specific case for the Japanese market. In fact, for any different situation, as long as a standard sample is assigned, the WD values can easily be used to evaluate the handle of fabrics for other markets.

Discussion

To show the advantages of the WD value more clearly, we can compare the two kinds of measures for fabric total handle evaluation, that is, the *THV* and WD values.

CALCULATION PRINCIPLE

The basis for Kawabata's *THV* value calculation is tactile assessment, and the influence of the subjective factors is hence inevitable. The principle for the WD value is purely mathematical and objective, and only through the standard sample does it relate to human sensory perception.

The equations for *THV* value calculation assume linear or at least monotonical relations between the parameters and the total handle of fabrics, which can be easily shown to be far from the real case. In our approach, however, the relative comparison principle with the concept of distance avoids dealing with these intractable relations, which are more likely subjects for the psychologists and beyond the area of textile science.

SUITABILITY FOR DIFFERENT MARKETS AND PRODUCTS

The unsuitability for other markets outside Japan is the main problem of Kawabata's method, where it is necessary to build the new equations one by one. But for WD value calculation, the only change required for a new market is to choose the corresponding standard sample.

As for the various fabric products, because the transformation matrix for WD value calculation must match the fabric type (this problem can be solved by a further mathematical process, which will be introduced in another paper), the corresponding matrix has to be derived for each specific fabric type. The amount of work in this procedure is much less than that in Kawabata's method, since in order to suit the different products, not only must the whole tactile assessment procedure be arranged, but all equations concerned must also be rebuilt. The tremendous amount of work involved often makes the **application** of this system impractical.

Conclusions

Although fabric handle is ultimately a subjective response to physical stimuli, there are clearly practical advantages in the development and commercial trading of textile fabrics to be gained from the replacement of the traditional subjective tactile assessment by an objective measurement evaluation method.

The Kawabata system of objective measurement and the evaluation of fabric handle, especially the KES-F instruments, is a significant contribution to the research of fabric properties. The inevitable problems existing in Kawabata's handle value calculation method have however, created difficulties for its practical application because the results rely on subjective assessment.

The new objectively calculated WD value we propose, through a more logical and rational mathematical process, is possibly feasible for total fabric handle evaluation because of its simplicity and suitability for different textile markets and fabric types.

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