

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

## Part II: Objective Measures for Primary Handle

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### ABSTRACT

The subject of fabric primary handle evaluation is discussed in this paper. Some problems existing in Kawabata's system for primary hand values are revealed, which are considered inevitable in an approach involving subjective sensory assessment. Based on the same theory introduced in Part I, a new proposal for the objective evaluation of primary handle is presented by which the necessary and sufficient number of primary handle terms and the corresponding primary handle values are obtained. The methods and results of determining and testing the physical meanings of these primary handle terms are also provided.

During the process of tactile sensory assessment of fabric handle, besides ranking fabrics according to handle preference, judges are used to expressing their senses in terms of a series words or phrases such as hard, thready, bulky, stiff, etc., to describe the ranking results of the finer levels. Kim [3] collected 144 such words, which were considered to be used frequently in the process of fabric handle assessment. Using these words, judges can communicate their subtle sensory perceptions when assessing primary handle.

When proposing the objective evaluation of fabric handle, it is also necessary to set two levels, so called "primary" handle and total handle, as in Kawabata's system. One possible reason is that this follows the tradition of tactile sensory assessment mentioned above. But when an instrument is used to measure fabric mechanical properties by which the objective handle value can be calculated,

In order to evaluate primary handle properly, the following essential problems must be solved: (a) How many basic components of primary handle will actually constitute total handle? These components, just as three primary colors, must be independent of each other or at least with different and clear meanings, so that they can be expressed by only a few definite words to simplify understanding and communication. (b) What relations can be found between these primary handle components and the mechanical properties and total handle of fabrics? In other words, how can we evaluate primary handle features by measurable mechanical properties?

### Problems of Kawabata's System

#### DETERMINING THE NUMBER AND TERMS OF COMPONENTS

Kawabata's method [ 1 ] defined three kinds of primary handle features (HV values) for men's winter suiting fabrics and four for women's as shown in Table I. Because the determination of these features was en

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We must admit that in a study of consumer products that directly serve people in daily life, subjective experiences play a very important role in quality evaluation, but a scientific system cannot be expected to build on a purely subjective sensory base. The proper method should follow the same direction cla#

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system and then to relate the results to subjective sensory perception.

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Only after fabric primary handle features like Kawabata's *koshi* and *numeri* have been determined it is then possible to specify total handle more completely and definitely.

#### The main difficulty in tactile sensory assessment

s. In fact, the meanings of these words or expressions, which are vivid indeed, are themselves sometimes overlapping and ambiguous. Obviously the results expressed by

these words cannot be expected to specify fabric primary handle clearly and reasonably

TABLE I. Kawabata's primary hand expressions and their definitions.

Japanese	Hand English -	Definition
Men's winter suit fabrics		
Koshi	stiffness	A feeling related to bending stiffness. A springy property promotes this feeling. A fabric with compact weaving density and springy and elastic yarns gives this feeling strongly.
Numeri	smoothness	A mixed feeling coming from smooth, limber, and soft feelings. The fabric woven from cashmere fiber gives this feeling very strongly.
Fukurami	fullness and softness	A feeling coming from bulky, rich, and well formed feelings. A springy property in compression and thickness accompanied with a warm feeling are closely related with this feeling. (Fukurami means swelling.)
Women's medium thickness fabrics		
Koshi	stiffness	Same as koshi above.
Numeri	smoothness	Same as numeri above.
Fukurami	fullness and softness	Same as fukurami above.
Sofutosa'	soft feeling	Soft feeling, a mixture of bulky, flexible, and smooth feelings.

'This is not a primary hand. This expression was added as a semi-primary hand because this feeling was important for ladies' dress fabrics.

#### THE PROBLEM OF UNCERTAINTY AND OVERLAPPING

To demonstrate this problem, the correlations between HV values revealed by Kawabata [ I ] are provided in Table II. In our research with 88 fabric samples, we used the KES-FB instruments and Kawabata's equations to obtain the HV values of these samples and the correlations between them (as shown in Table III), which are consistent with those of Kawabata.

Tables II and III show that fairly high correlations exist between each pair of HV values. In particular, those between numeri (smoothness) and fukurami (fullness and softness) and numeri and sofutosa (soft feeling) are as high as 0.8-0.9 or more. It is therefore difficult to consider these HV values as specifying dif-

TABLE III. The correlations between Kawabata's HV values for medium thickness fabrics (M = 88).

Koshi	Numeri	Fukurami
Koshi	1	-0.268
Numeri	0.902	1
Fukurami	0.866	0.837

ferent features of primary fabric handle. During the tactile assessment process, the Japanese judges understood and grasped the definitions of these primary handle values in a vague and overlapping manner. This situation is inevitable with the sensory assessment process, no matter what country the judges come from.

TABLE I. Correlation between three primary hands of fabrics.

	Koshi	Numeri	Fukurami	THV
Men's winter suit fabrics (N = 214)				
Koshi	1.0000	-0.4390	-0.2515	-0.2237
Numeri	-0.4390	1.0000	0.9040	0.8661
Fukurami	-0.2515	0.9040	1.0000	0.8378
TH V	-0.2237	0.8661	0.8378	1.0000
Women's medium thick fabrics (N = 220)				
Koshi	1.0000	0.1745	0.4435	-0.0869
Numeri	0.1745	1.0000	0.7417	0.8628
Fukurami	0.4435	0.7417	1.0000	0.7297
Sofutosa	-0.0869	0.8628	0.7299	1.0000

THE PROBLEM OF MEANING INSTABILITY

Table II shows that for different kinds of fabrics, the correlations between the same pair of HV values vary. To show this more clearly, for each HV value, the prior five parameters [ 1 1, which are the most significantly correlated with this HV value, are selected from all the mechanical parameters measured on the KES-FB instruments and listed in Table IV in the order of their correlation values. Table IV shows our results, which reveal that for different fabric types, the correspondence of a certain HV value with mechanical properties varies. Taking numeri as an example, among the five parameter sets of two numeris for different fabrics in Table IV, only the terms MMD and SMD are consistent. It is therefore unreasonable to take these numeris as an identical primary handle feature, although there is (as there should be) only one definition for numeri in Kawabata's system. Apparently, during those sensory assessment processes in Japan, numeri was granted the distinct meanings for different types of fabrics. Table V provides the meanings and the definitions of the parameter symbols.

Certainly the total handle of various fabrics should include the different terms of primary handle. The meaning of a certain term of primary handle must be stable, however, and the relation with mechanical properties of fabrics must also be definite and unchangeable, just as the differences between various colors depend only on the proportions of the three primary colors.

In the process of creating Kawabata's system, each of the primary handle values was placed in one of 11 classes numbered from 0 to 10 according to the results of tactile sensory assessment of the Japanese judges. For such precise levels, it was very difficult to eliminate the diversities of the assessment results from person to

TABLE V. Characteristic values of basic mechanical properties.

Blocked properties	Symbols	Characteristic value	Unit
Tensile	LT	linearity	-
	WT	tensile energy	gf•cm/cm'
	TR	resilience	%
Bending	B	bending rigidity	gf • cm./cm
	2HB	hysteresis	gf. • cm'/cm
Shearing	G	shear stiffness	gf/cm • degree
	2HG	hysteresis at 0 = 0.5°	gf/cm
	2HG5	hysteresis at m = 5°	gf/cm
Compression	LC	linearity	-
	WC	compressional energy	gf • cm/cm=
	RC	resilience	%
Surface	MIU	coefficient of friction	-
	MMD	mean deviation of MIU	-
	SMD	geometrical roughness	micron
Weight	W	weight per unit area	mg/cm2
Thickness	T	thickness at 0.5 gf/cm'	mm

person and time to time. The difficulties in understanding, communicating, and mastering the definitions of various primary handle features during the whole assessment process made the situation worse. Herein lies the crux of all the problems.

A New Proposal of Objective Specification

In the Part I of this paper, we used the KahunenLoeve (K-L) orthonormal expansion theory to transform the original matrix into a new one by which we derived an objectively calculated WD value for total fabric handle. The proposal of objective evaluation for primary handle introduced here also has the same theoretical base. The whole process is briefly reviewed as follows:

According to the K-L theory, an original data matrix X, which is created from the mechanical property pa-

TABLE IV. The closest parameters with Kawabata's primary hand terms (see Table V for definitions).

	Parameters					
Men's winter suit fabrics (sample number M = 214)						
Koshi	B	W	G	2HG5	LT	
Numeri	MMD	SMD	WC	B	2HG5	
Fukurami	WC	MMD	T	SMD	RC	
Women's medium thick fabrics (M = 220)						
Koshi	W	B	2HB	T	G	
Numeri	MMD	RC	MIU	SMD	W	
Fukurami	T	W	WC	MMD	RC	
Sofutosa	MMD	RC	WC	T	LT	
Medium thick fabric (M = 88)						
Koshi	B	W	RT	WC	G	
Numeri	MMD	RC	MIU	T	SMD	
Fukurami	RC	T	WC	MMD	MIU	

parameters of fabric samples, can be replaced by a new matrix Y, the components of which are called the features of the original data:

$$Y=XR, \tag{I}$$

where X = (X<sub>1</sub>, X<sub>2</sub>, . . . X<sub>n</sub>) is the original data matrix with n components of measured mechanical parameters; R = (R<sub>1</sub>, R<sub>2</sub>, . . . R<sub>p</sub>) (p × n) is the transformation matrix, the components of which are p n-order eigenvectors of the covariance matrix Y of the original data X; and the new matrix Y = (Y<sub>1</sub>, Y<sub>2</sub>, . . . Y<sub>p</sub>) is the result of transformation.

Geometrically, the transformation is a rotation or projection from an axis system defined by values of X<sub>1</sub>, X<sub>2</sub>, . . . X<sub>n</sub>, to an orthogonal axis system defined by Y<sub>1</sub>, Y<sub>2</sub>, . . . Y<sub>p</sub>.

The components of the new matrix Y = (Y<sub>1</sub>, Y<sub>2</sub>, . . . Y<sub>p</sub>) can be demonstrated to contain all information about fabric mechanical properties, i.e., fabric handle, in the original data without loss. In general, p < n, that is

The matrix

Y is orthonormal, meaning that a

$\sum_{i=1}^p Y_{ij}^2 = 1$

So it is then reasonable to take the components of matrix Y as the objective measures to represent primary fabric handle.

$$\sum_{i=1}^p Y_{ij}^2 = 1 \tag{II}$$

and sufficient number of primary handle terms is determined as p. The problem remaining is how to ascertain the practical meaning of each component.

Because there are neither clear and unambiguous definitions nor an objective and reliable calibration for both total handle and primary handle values, it is difficult to determine the physical meanings of these components directly. This problem does not affect the application of this approach seriously, however. In general, we can denote them as, for example, the first, second, . . . pth primary handle values sequentially; by practical application and experiments, the correspondences between these p features with the primary handle feelings of sensory assessment can be gradually derived. As an expedient choice, however, the corre-

lation analysis is used in this paper to relate these features to other existing results such as Kawabata's HV values and some conventional index. The details are discussed in the next section.

## Calculation and Nomenclature

### DETERMINING NECESSARY AND SUFFICIENT TERMS

Note that because we are able to compress information, the K-L transformation condenses the original n parameters into p isolated components, which still completely represent the original parameter set.

Because the p features are independent of (or uncorrelated with) each other, they illustrate p different aspects of fabric mechanical properties, i.e., total fabric handle. It is therefore natural to take these features as the measures of primary fabric handle.

The whole fabric set can be divided into many types in terms of fabric thickness or weight per unit area. The characteristics of fabric handle for these different types are quite diverse. For the convenience of discussion, all analysis in this paper concentrates on the medium thickness fabrics, though the method can be used to tackle other fabrics in exactly the same way.

Using M = 88 medium thickness suiting fabrics, each having n = 16 mechanical parameters measured by KES-FB system, the original matrix X is formed. The range of the fabric samples is shown below:

	Max.	Min.	Mean	Var.
Weight, mg/cm <sup>2</sup>	31.39	19.58	26.12	2.45
Thickness, mm	0.92	0.54	0.68	0.09

The pre-processing of the original data and the calculation of the covariance matrix V as well as the n eigenvalues and associated eigenvectors were introduced in Part I of this paper. To save space, only the prior eight eigenvalues are listed in Table VI with their corresponding ratios  $W_i = C_i / \text{tr } V$ , (i = 1, 2, . . . 8). The value of p is determined by the condition [2], i.e.,

$$\sum_{i=1}^p W_i \geq 0.85, \tag{2}$$

TABLE VI. The prior eight eigenvalues and their ratios.

i	1	2	3	4	5	6	7	8
C <sub>i</sub>	4.032	3.120	2.304	1.440	1.200	0.816	0.672	0.656
W <sub>i</sub>	0.252	0.195	0.144	0.090	0.075	0.051	0.042	0.041
E W <sub>i</sub>	0.252	0.447	0.591	0.681	0.756	0.807	0.849	0.890



where  $tr V = \sum_{k=1}^p C_k$  is the trace of matrix V. So from

Table V,  $p = 8$  is chosen as the number of the primary handle values. On the other hand, the sixteen mechanical parameters measured with KES-FB instruments reflect eight different primary handle terms. According to the value of p, the transformation matrix R in Equation I is then composed with the p eigenvectors

$R_i$  ( $i = 1, 2, \dots, p$ ) associated with these prior p eigenvalues and, after the transformation, the feature matrix Y with  $p = 8$  components, i.e., eight primary handle values of a fabric sample, is derived. For the sake of convenient application, the components are linearly modified to ensure their values within the range of 0-10. Apparently these eight primary handle features can specify fabric handle more completely and rationally.

NOMENCLATURE OF PRIMARY HANDLE FEATURES

In order to ascertain the practical meanings of these eight features, we first used the correlation analysis approach. The correlation coefficients between all eight features ( $Y_i$ ;  $i = 1, 2, \dots, 8$ ) and the sixteen original mechanical parameters ( $X_1, X_2, \dots, X_{16}$ ) are calculated and listed in Table VII. Then, using Kawabata's equations for primary hand calculation, the HV values of these samples are obtained and the correlations between the HV values and the eight features are shown in Table VIII. Although we have pointed out the shortcomings of HV values, here we have to use them to demonstrate the new measures because we have no better standard.

Table VIII shows that Y1, the first of eight features, is most significantly correlated with Koshi (stiffness of

TABLE VIII. The correlations between Y, and Kawabata's primary hand values ( $M = 88$ )'

	Koshi Numeri	Fukurami
Y1	0.557" -0.139	0.101
Y2	-0.586"	
Y3	0.591" 0.237"	0.593"
Y4	-0.136 -0.347"	0.112
Y5	0.471" -0.046	-0.367"
Y6		0.528" 0.527"
Y7	-0.265' -0.080	-0.176
Y8	-0.069 -0.061 -0.051 0.062	-0.147 0.2520

'\*Significant at the 0.05 level, "significant at the 0.01 level

Kawabata's system) and is called "stiffness" accordingly. Similarly YZ and Ys are called "fullness" and "smoothness," respectively. The remaining five features can be named according to the results of Table VII: for example Y3, which is significantly correlated with the surface friction properties MMD, SMD, weight W, and thickness T, and is the condensed result of these parameters, can be designated as "crispness," reflecting the crisp property of fabrics. Y6 is associated with the tensile energy WT, resilience RT, and compressional resilience RC, and it can be termed "elasticity" or something similar. Y8, corresponding to the tensile linearity LT, bending rigidity B, shear stiffness G, and compressional resilience RC, is named "droopiness." For similar reasons, Y, and Y5 are named "roughness" and "softness," respectively.

For example, it is difficult to explain why to call Ys smoothness instead of fullness, whose correlation with YS is also high in Table VIII; the only reason here is the nomenclature for other features.

fault, however, is mainly due to the overlapping mean

TABLE VII. The correlation between eight features and the sixteen KES-FB parameters (samlebe  $M = 88$ )'

	p															
Y,	Y1	Y3	Y,	Ys	Ys	numr		ye								
T	.186	-.281'	-.244'	.229'	.296"		-.167	-.458"		-.316						
WT	-.245'	-.161	.168	-.182	.245'		.548"	-.225'		.144						
T	-.058	-.154	.194	-.354"		-.341"	-.562"		.1 SS	.093						
	.301"	-.250"	.319"	-.086		.0S I	-.208		-.136	-.359						
HB	.461"	.019	.070	-.028		-.094	.068		.049	-.251						
G	.334'	-.242'	-.162	-.233'		-.024	.009		-.062	.542						
HG	.435"	.017	-.190	.069		-.029	.212		.162	-.008						
HGS	.425"	-.074	-.251'	.002		-.035	.107		.143	.266						
G	.166	.433"	.062	-.052		.117	-.104		-.173	-.035						
WC	.119	.507"	.145	.165		.001	.029		.210	.084						
C	.093	.239'	.127	-.238'		.506"	-.306"	-.331"		.369						
RIU	.024	.124	.063	.276'		-.625"	.063	-.645"		.197						
MMD	.074	-.200	.403"	.431"		.014	-.108		.057	.278						
MD	.03 t	-.233'	.3S I'	.466"		.211	-.011		.194	.179						
S	.219'	.293"	.407"	-.089		.018	.167		-.038	-.138						
T	.113	-.218	.383"	-.386		-.130	.32U"		-.0S2	-.0S9						

"Significant at the 0.05 level, "significant at the 0.01 level.

because of the uncorrelated property of these eight features, which have never been derived by other studies on this subject, these features do indeed describe fabric handle from different points.

110MM, M-1

is possible that the names designed for these features are not entirely consistent with the original meanings of these words or with the results of sensory assessment in term of these words, but is is not difficult to solve this problem gradually through practice.

For further discussion, in order to avoid complexity in the beginning, we prefer to take a smaller number of these eight primary handle terms and to check them with other methods. ~1~111

As an alternative, we have adopted some well-known conventional experiments here to provide evidence for the conclusion above. For the test of stiffness, the methods used are bending length (flexometer), hanging loops, and the vibration techniques. The principle of the last method is based on the correlation between the resonance frequency and the stiffness of a fabric strip when vibrated.

After the tests using all these methods, we calculated the correlations between the term stiffness and the results derived from three methods and presented them in Table IX. The high values of the correlation demonstrate the reasonableness of the nomenclature for stiffness.

TABLE IX. The correlations of other tests with stiffness (M = 30).

Test	Correlation
Bending length	0.927
Hanging loop	0.875
Vibration method	0.832

For the test of fullness, the results in Table VII provide the evidence. The correlations of fullness ( Yz) with the compressional parameter set, including LC, WC, and RC, are apparently higher than those with other property parameter sets, while fabric compression is considered the main factor dominating the fullness of primary fabric handle (see the definition for Fukurami in Table I).

The most difficult test may be proving smoothness, for it seems very laborious to collect the fabric samples

with gradually different surface properties or to find the measurable relevant parameters. To solve this problem, we adopted a plasma etching technique. A number of samples from the same fabric were processed with plasma for different periods of time. While processing, the surface state (i.e., the smoothness) of samples was modified according to a known tendency: the longer the processing time, the less smooth the sample surface. These changes could be identified even by tactile sensory perception. The comparison of the processing time and the value of stiffness after each process are provided in Table X, and the values of stiffness and fullness are also included to show the influences of the plasma process on these two terms. The monotonic decrease of smoothness with processing time demonstrates the changes of fabric surface and also the feasibility of this term. We show as well that the process significantly enhances stiffness, but there is slight influence on fullness.

TABLE X. The influences of the plasma etching process on the values of three primary handle features.

Processing time, minutes	2	5	10	IS
Stiffness	4.324	5.772	7.727	8.653
Smoothness	6.461	5.210	3.882	3.109
Fullness	6.257	5.788	5.609	5.421

## Discussion

As with Part I of this paper, we wished to compare the primary handle features derived in this paper with those of Kawabata. The first characteristic of our proposal is objectivity without any influence of subjective factors. In fact the primary handle concepts of stiffness, smoothness, etc., are less subjective than the "preference" of total handle, so they should be more suitable for the objective approach.

The definitions of these features are stable and unchangeable for diverse fabrics, and are not like HV values. The lack of correlation between the features eliminates the problem of overlapping meaning in HV values. And the problem of uncertain numbers or terms of primary handle values is solved by determining the necessary and sufficient number p in this paper.

It is easy to derive the relationship of these features to total fabric handle, because in the Part I of this paper, we directly calculated the objectively measured WD value for total handle from these features. Owing to the difficulties of definition and calibration, however, an objective evaluation of primary handle is even more difficult than that of total handle. There is still much

work required so that this objective proposal can replace sensory assessment. The most important work is to create the objective standards of primary handle terms for further research.

### Conclusions

In order to specify fabric handle more precisely, it is necessary to set a middle level between the mechanical properties and total fabric handle. The method of sensory assessment in evaluating primary handle creates a bigger problem than for total handle because of influences of subjective factors.

We have demonstrated that the sixteen mechanical properties contain eight independent components, which can be considered as the primary handle features composing total fabric handle. It is impossible to evaluate so many different primary handle terms by sensory assessment alone. These eight components can be de-

rived theoretically, and their practical meanings can be determined experimentally.

To eliminate the difficulties in evaluating primary fabric handle, one must build the objective standards for defining and calibrating primary fabric handle terms. The various methods used in colorimetry to deal with similar problems may be useful.

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