Measurement of Fabric Hand Evaluation Values by Neural Network Based on PCA of Drape Images

Jiro OKAMOTO*, Shigeyoshi NAKAJIMA† and Shoichi HOSOKAWA‡

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Synopsis

Hand evaluation (HE) "FUAI" in Japanese is very important values to evaluate fabric qualities and is measured by KES system until now. HE values are obtained by the functions of 16 mechanical properties measured by KES system. Fundamentally these HE values should be evaluated by the feeling of fabric experts hands and be expressed by HE values between 0 to 10 grades, but both method are bothersome.

In this paper, we proposed a new method to evaluate HE values by means of neural network of which inputs are the FFT spectrum of drape image. Drape image is obtained by a roundly cut fabric hung on a little round column, where both centers coincide. This method is very simple.

KEYWORDS: Hand evaluation, fabric, neural network, drape image, FFT spectrum

1 Introduction

It is important to evaluate fabric feeling, that is, fabric quality by some standard evaluation values. As one of these evaluation methods there exists the hand evaluation (HE) method. The feeling of fabrics , that is HE, is called "FUAI" in Japanese.

HE is fundamentally evaluated by hand feeling of fabric experts as five kinds of HE values such as Stiffness (KOSHI), Anti-drape stiffness (HARI), Crispness (KISHIMI), Fillness and Softness (FUKURAMI), and Scrooping feeling (KISHIMI), each of them consists of 11 grades ($0 \sim 10$) [1] .

In 1972, Hand Evaluation and Standardization Committee (HESC) was established in the Textile Machinery Society of Japan and HE was standardized. In 1975, instruments named KES-F system was designed by HESC, which was a measuring system of mechanical properties of fabric, and these properties are divided into 6 blocks including 16 kinds of mechanical property values. HE values can be evaluated by equations consisting of these values. This system needs 16 kinds of measurements by using KES system constructed by four instruments, so that it is very bothersome [1].

The method we proposed previously was a simpler one to obtain HE values by using only drape image (or shape or wave) of circularly cut fabric (its diameter is 20 cm), which is hung on a little round column (its diameter is 5 cm) naturally and softly, where both centers coincide [4]. In this paper, we report the effectiveness of this proposition through experiments using real materials. PCV (principal component values) of drape image can be obtained by its FFT, and these values are inputted to the neural network (NN) in order to avoid bothersome measurements by

*Associate Professor, Department of Information and Communication Engineering
†Research Associate, Department of Information and Communication Engineering
‡Professor, Department of Information and Communication Engineering

KES system. We proved that, as the FFT spectrum of drape image reflects fabric qualities, it may be possible to evaluate HE values by the drape image.

Based on this proposition, we constructed a NN which is able to evaluate HE values obtained by KES system as outputs. In the case of learning of the NN, we used 12 kinds of fabrics. Two kinds of them other than these 12 kinds are used to test whether the NN learned works correctly.

In the end of this paper, we concluded that this system worked fairly well. Further we proposed an improved method for this system and suggests that these method may be anticipated in future development of HE measurement and the related psychological measurements.

Table 1: Characteristic parameters of basic mechanical properties used in the KES System

Block	Mechanical property	*i*	*symbols*
1	Tensile property	1	LT (Linearity)
		2	$\log WT$ (Tensile energy)
		3	RT (Resilience)
2	Bending property	4	$\log B$ (Bending rigidity)
		5	$\log 2HB$ (Histeresis)
3	Shearing property	6	$\log G$ (Shear Stiffness)
		7	$\log 2HG$ (Histeresis)
		8	$\log 2HG5$ (Histeresis)
4	Compressional property	9	LC (Linearity)
		10	$\log WC$ (Compressional energy)
		11	RC (Resilience)
5	Surface property	12	MIU (Coefficient of friction)
		13	$\log MMD$ (Meandeviation of MIU)
		14	$\log SMD$ (Geometrical roughness)
6	Weight and thickness	15	$\log T$ (Thickness at $0.5gf/cm^2$)
		16	$\log W$ (Weight per unit area)

2 HE of Fabrics

Mainly there are five words expressing HE; "FUAI", such as "KOSHI", "HARI", "SHARI", and "KISHIMI" as mentioned previously. In 1972 HESC defined the words expressing HE and the strict definition of them. Then, the committee proposed a method to measure the mechanical properties of fabrics and the measuring instruments for them. The measuring instruments were called KES system. By using these mechanical properties measured by this system, HE values were able to be obtained approximately by the equations without bothersome HE by experts [1].

At the same time, the fundamental HE was established by this HESC. The kinds of HE were different from objective fabrics. For example, HE for Men's winter suit fabric is composed of three kinds (KOSHI, NUMERI and FUKURAMI), and for men's summer suit fabrics, it is composed of four kinds (KOSHI, SHARI, FUKURAMI and HARI). In this paper, we only treat women's thin dress fabrics, for which five kinds of standard HE values such as KOSHI, HARI, SHARI, FUKURAMI and KISHIMI are defined. The strict definitions for them are shown in Table 3 [1].

3 Measurement of the Mechanical Properties of Fabric by KES System.

HESC established not only the standardization of HE but also constructed the way of measurement of the mechanical properties of fabrics by specially designed instruments named KES system and introduced the translation formulae for obtaining HE values from these measured property values.

The mechanical properties concerning fabric are grouped into six blocks as follows;

G1: Tensile property	G4: Shearing property
G2: Bending property	G5: Compressional property
G3: surface property	G6: Weight and thickness

These values excluding weight and thickness are able to be measured by KES system. These blocks are made of 16 kinds of characteristic values in detail, in which 11 kinds of them are transformed into logarithms as shown in Table 1. The HE values Y for each kind is expressed by the most simple linear equation consisting of 16 mechanical properties x_i of fabric as follows;

$$Y = C_o + \sum_{i=1}^{16} C_i \frac{x_i - \overline{x_i}}{\sigma_i}, \tag{1}$$

where C_0 and C_i are constant parameters, $\overline{x_i}$ and σ_i are the mean and the standard deviation of the i-th mechanical property respectively. The parameters for women's thin dress fabrics are shown in Table 6 and 7 in Appendix. The mean HE values of three samples obtained by KES system for 14 kinds of sample fabrics are shown in Table 2.

4 Drape and PCA

4.1 Drape

Drape is generally a name for a three dimensional curved surface which is obtained when a cubic body like human body is covered with a plane fabric. Drape is observable and shows all the properties of fabric relating to stiffness, smoothness, weight and so on.

Accordingly we could estimate the goodness of the fabric by the observation of the drape image of fabric. The fabric image hung on a column is observed at the straight upper site of this column by a video camera and we get a drape image by this camera. We called the distance from the center of round column to the edge of

Table 2: HE values for experimental fabrics obtained by the KES system

no.	Materials	KOSHI	HARI	FUKURAMI	SHARI	KISHIMI
0	hemp	8.970	11.129	1.926	5.891	4.552
1	silk	6.042	5.782	2.573	4.101	4.808
2	wool	7.212	7.671	2.186	5.596	4.067
3	vinylon	7.488	10.986	1.798	4.248	2.283
4	acryl	6.542	9.825	2.130	2.921	1.963
5	rayon	8.171	11.314	-0.199	6.233	2.769
6	acetate	7.901	11.548	0.790	2.901	2.087
7	nylon	7.199	10.534	1.052	1.628	1.980
8	polychlorinatevinyl	10.104	13.063	0.229	6.215	3.940
9	polypropylene	7.105	11.028	1.653	3.927	1.569
10	polyurethan	6.049	8.372	3.353	1.802	2.664
11	cotton	5.945	8.506	3.296	1.696	2.374
12	cuprene	6.927	9.272	1.943	3.957	2.853
13	polynosic	7.895	11.274	1.914	4.076	2.669

the drape image as the amplitude of the drape image. We chose the position of the most large amplitude as a starting sampling point.

The round drape image is sampled at 32 equally separated positions (equal angles) from the starting point. Before sampling, the image obtained by the camera is filtered through a median filter to remove random noise and after this preprocessing, the image is thinned by Laplacian filter and finally is digitized into a digital image of which pixels are consist of zero or one through a threshold, and then an outline of the drape image is extracted. To express this image in a graph, the sampling order (angles) is selected on the horizontal axis and the amplitude is selected on the vertical axis, and the image is plotted on this graph. We call this graph as a drape wave (See Fig1, 2 and 3).

This wave is transformed into Fourier spectrum by FFT which is its principal components as mentioned in the next subsections. The independent components are 16(complex numbers) out of 32 components. The inputs numbers to the neural network is totally 17 values including a direct component which is the mean amplitude of the wave (16 components are FFT amplitudes). We got three drape samples for each kind of fabrics used for our experiments.

By using this Fourier spectrum as the inputs to the neural network, we can easily obtain HE values without measuring a lot of mechanical properties of fabric by KES system.

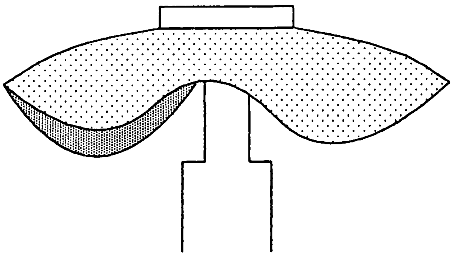

Figure 1: Drape image hung on a round column (Side view).

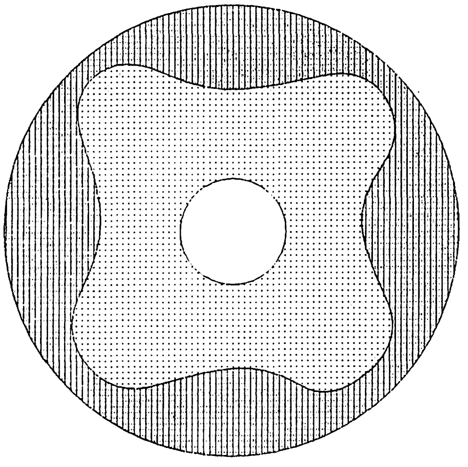

Figure 2: Drape image hung on a round column (Top view).

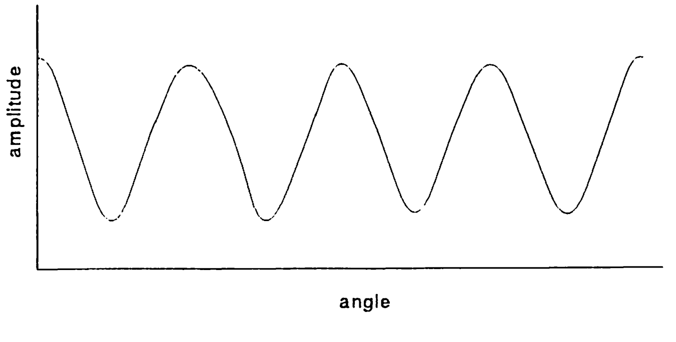

Figure 3: Drape wave where the abscissa shows sampling angles and the vertical axis shows its amplitudes.

4.2 Principal Component Analysis and Drape Wave.

The Principal Component Analysis (PCA) is a method to rearrange the information of p characteristic values composed of $x_1, x_2, ..., x_p$ into the smaller number of m composite characteristic values z_i (those are called principal components(PC's) where $m \leq p$) [2]. These composite characteristic values are expressed by the first order linear equations of original valuable x_i as follows;

$$\begin{aligned} z_1 &= l_{11}x_1 + l_{12}x_2 + ... + l_{1p}x_p \\ z_2 &= l_{21}x_1 + l_{22}x_2 + ... + l_{2p}x_p \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ z_m &= l_{m1}x_1 + l_{m2}x_2 + ... + l_{mp}x_p \end{aligned} \quad (2)$$

where, $\Sigma_{i=1}^{p} l_{ki}^2 = 1, \quad (k = 1, 2, ..., m)$.

The coefficients l_{ki} for these PC's are selected as these m PC's are mutually independent, and as the information contained in p valuables is concentrated on these PC's as large as possible in order. Closely examining these PC's for the objects, we can easily estimate the difference in the object group or can easily separate the group into certain subgroups.

4.3 PC's of Drape Wave and Fourier Transform.

A drape wave is sampled at p points and expressed by a vector $\mathbf{x} = (x_1, x_2 \cdots x_p)^t$, and let A be a covariance matrix of $\mathbf{x}$, and λ_i be an eigen value of A, and γ_i be its eigen vector and normalize as $||\gamma_i|| = 1$, where $\lambda_1 \geq \lambda_2 \geq, ..., \geq \lambda_p$. Let define new variable z_i as follows;

$$z_i = l_{i1}x_1 + l_{i2}x_2 + \cdots + l_{ip}x_p, \qquad \Sigma_{j=1}^{p} l_{ij}^2 = 1 \quad (3)$$

Then, the coefficient l_{ij} which maximizes the mean square value $E(z_i^2)$ becomes an eigen vector γ_i. That is, $z_i = \gamma_i{}^t\mathbf{x}$ results in the i-th PC which is independent of $z_j (j < i)$ and is the i-th largest PC variable. The (i, j) element of A is able to put $r_{|i-j|} = E(x_i x_j)$ according to the cyclical characteristic of the drape wave, and treating the drape wave as the wave which has a repeating cycle p, we are able to put $r_{p-i} = r_i$.

As A is a symmetric and cyclic matrix as

$$A = \begin{pmatrix} r_0 & r_1 & \cdots & r_{p-1} \\ r_1 & r_0 & \cdots & r_{p-2} \\ \vdots & \vdots & \ddots & \vdots \\ r_{p-1} & r_{p-2} & \cdots & r_0 \end{pmatrix}, \quad (4)$$

then, the eigen value of cyclic matrix is given by [3]

$$\lambda_i = r_i\omega^{i0} + r_1\omega^{i1} + \cdots + r_p\omega^{i(p-1)} \quad (5)$$

where

$$\omega = \exp(-2\pi j/p). \quad (6)$$

On the other hand, the eigen vector is given by $\gamma_i = (\omega^{i0}, \omega^{i1}, \cdots, \omega^{i(p-1)})^t$. γ_i is a kernel of discrete Fourier transform, and as PC becomes $z_i = \gamma_i{}^t\mathbf{x}$, z_i is the i-th spectrum of the discrete Fourier transform of $\mathbf{x}$. It means that the PC's of the drape wave are obtained by the Fourier spectrum of drape wave, that is, the PC's of the drape wave are given by the FFT of $\mathbf{x}$. The PCA is based on the eigen values and eigen vectors of covariance matrix A. The eigen value λ_i of A, as is easily understood by Eq.(5), is the spectrum of autocorrelation r_i of $\mathbf{x}$, so that it is proportional to the square value of the amplitude of FFT spectrum of $\mathbf{x}$, that is, the power spectrum. The value λ_i shows the divergence of the i-th PC. The bigger the i-th PC is, the more it contributes in the i-th PC.

5 HE Learning of Neural Network

5.1 Neural Network

To obtain the HE values of fabrics, we used Fourier transform of the drape wave as the input to the NN which has the learning ability to obtain HE values. We used BP(Back Propagation) algorithm for learning and adopted the learning rate as 0.1 and momentum as 0.9.

5.2 Materials of Experiment

The materials of fabrics used in this experiment are all plain fabrics. All of them have different qualities and their HE values obtained by KES system are shown in Table 2(each value is the average of three samples) In these materials, 12 samples of upper side from 0 to 11 are used to learning and lower side materials numbers 12 and 13 (cuprene and polynosic) are used for evaluation whether the network is properly learned.

5.3 Learning of HE values by NN

We used totally 17 inputs to the NN including 16 frequency spectra and mean amplitude as mentioned before. Its outputs are five kinds of HE values (Table 2) which were obtained by Eq.(1) where the values in the Tables 6 and 7 for the evaluation of women's thin fabric were used.

The teaching signals for outputs were normalized to the range from 0.0 to 1.0. However, taking into consideration of the deviation in experiment, we normalized the larger extent of (-4.0 to 14.0) instead of real HE values (0.0 to 10.0). We set the allowable mean square error, that is, the mean square difference between the target values and the output values of neural network as 0.00004. This value is 0.1 ($\sqrt{0.0004} \times 18$) in conversion to HE values, and set the maximum learning cycles as 50000 cycles.

We first used three layer NN, but it did not converge fully, so we used four layer NN. After several trials, we got the optimum NN for this experiment as; (1) the number of units for the first (input) layer is 17, (2) the number of units for the second layer is 25, (3) the number of units for the third layer is 25, (4) the number of units for the output layer is 5. Learning rate is 0.1 and momentum is 0.9.

Table 3: Definition of HE

	Japanese	English	HE Definition
1	KOSHI	Stiffness	A feeling related with bending stiffness. Springy property promotes this feeling. The fabric having compact weaving density and woven by springy and elastic yarn makes this feeling strong.
2	HARI	Anti-drape stiffness	Anti-drape stiffness, no matter whether the fabric is springy or not.
3	FUKURAMI	Fullness and softness	A feeling comes from bulky, rich and well formed feeling. Spring property in compression and thickness accompanied with warm feeling are closely related with this feeling.
4	SHARI	Crispness	A feeling comes from crisp and round surface of fabric. This feeling is brought by hard and strongly twisted yarn. This feeling brings us a cool feeling.
5	KISHIMI	Scrooping feeling	Scrooping feeling. A kind of silk fabric possesses this feeling strongly.

5.4 Results of learning

We trained the neural network as mentioned above. Average learning epochs of termination was about 30690. In Table 4, the mean square errors after the end of the learning are shown. It contains the average values for five kinds of HE values for 12 kinds of materials. In the Table, maximum mean square error is 0.000347 for "HARI" of the sample No.3 (vinylon). As this value is 0.335 to be converted into HE value, it may be said that the NN had converged to an allowable range of very little error for all sample fabrics.

5.5 Test of the learned NN

To test whether the NN were correctly learned, we obtained the HE values for non-learned samples, cupula and polynosic, where both of them contained three samples respectively. The values in the Table 5 show the mean square errors of HE values for two fabrics those are converted into HE values from the output values.

As the mean square errors of HE values to cupula fall into a range between 0.6 and 1.1, we can conclude that the results of this test may be successful. On the other hand, the mean square errors of HE values to polynosic are larger than those of cupula, but they are not so large comparing to the allowable value one that these results seem to be successful. Nevertheless, especially for "HARI", the error is two and considerably large. We may mention in the next paper about the improvement method to this error.

Table 4: mean square errors after learning

material no.	KOSHI	HARI	FUKURAMI	SHARI	KISHIMI	average
0	0.000052	0.000090	0.000000	0.000008	0.000009	0.000032
1	0.000017	0.000038	0.000000	0.000003	0.000002	0.000012
2	0.000043	0.000045	0.000009	0.000004	0.000010	0.000022
3	0.000027	0.000347	0.000000	0.000009	0.000013	0.000079
4	0.000021	0.000058	0.000007	0.000001	0.000020	0.000022
5	0.000030	0.000085	0.000039	0.000013	0.000046	0.000043
6	0.000041	0.000019	0.000065	0.000048	0.000054	0.000046
7	0.000023	0.000020	0.000163	0.000026	0.000050	0.000056
8	0.000215	0.000011	0.000006	0.000083	0.000032	0.000070
9	0.000008	0.000054	0.000004	0.000049	0.000002	0.000023
10	0.000012	0.000084	0.000029	0.000004	0.000014	0.000029
11	0.000023	0.000042	0.000071	0.000028	0.000071	0.000047
average	0.000043	0.000074	0.000033	0.000023	0.000027	0.000040

Table 5: Errors of HE values when only FFT spectrum is used

No.	KOSHI	HARI	FUKURAMI	SHARI	KISHIMI	average
12	0.546856	1.034178	1.080600	1.113675	0.728055	0.928004
13	0.871839	2.001483	1.298747	1.475122	0.953830	1.381199

6 Conclusions

In this paper, our proposed method to obtain HE values for fabrics by using FFT spectrum of drape wave to the input of the NN which has learning ability was proved to be effective. As the FFT spectrum of drape wave is the PC of its shape, the system may be effective. To demonstrate its effectiveness we used 12 samples of fabrics for learning and after that we confirmed the accuracy of the learned NN for the other two sample fabrics those were not used for training terms, and got fairly well results. There is still left the improvement problems of HE values for such as HARI, which has much error, in the future subject.

Generally these method using PCA may be effective for the evaluation of the psychophysical quantities, such as the evaluation of noise or taste, those need psychological judgment.

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Appendix

Table 6: $\bar{X}_i$ and σ_i for woman's thin dress fabric

Block	i	X_i	$\bar{X}_i$	σ_i
1	1	LT	0.5906	0.0939
	2	$\log WT$	1.0551	0.2728
	3	RT	43.0828	12.0448
2	4	$\log B$	-1.7749	0.3592
	5	$\log 2HB$	-2.0351	0.5126
3	6	$\log G$	-0.3731	0.3044
	7	$\log 2HG$	-0.2733	0.5586
	8	$\log 2HG5$	0.0295	0.4506
4	9	LC	0.4483	0.1109
	10	$\log WC$	-0.9951	0.3174
	11	RC	49.4168	11.6778
5	12	MMU	0.2258	0.0452
	13	$\log MMD$	-1.6832	0.2191
	14	$\log SMD$	0.4892	0.3999
6	15	$\log T$	-0.4253	0.2209
	16	$\log W$	0.9623	0.1768

Table 7: C_i for woman's thin dress fabric

	C_i				
i	KOSHI	HARI	FUKURAMI	SHARI	KISHIMI
0	5.1991	5.0816	4.7891	4.6833	4.0158
1	0.0003	0.1272	0.0399	0.0189	0.0205
2	-0.3688	-0.2409	0.1015	-0.1181	-0.4831
3	0.0242	0.1212	0.1264	-0.0982	-0.0557
4	1.2622	1.8527	0.0474	0.0770	-0.0218
5	-0.3961	0.0462	0.0199	-0.0602	0.1018
6	-0.0247	0.2238	-0.0018	-1.1854	-0.1765
7	-0.4317	-0.1366	0.0134	-0.0112	-0.8711
8	0.1781	0.1281	0.0104	0.0012	0.1120
9	0.0561	0.1163	-0.2820	0.0674	-0.0504
10	0.1096	-0.0361	0.4589	0.0469	0.1902
11	0.0285	0.0164	-0.1401	0.2745	0.0314
12	-0.0596	-0.0119	0.5535	-0.1014	0.0834
13	0.1760	0.0999	-0.6889	1.0850	-0.1089
14	-0.0537	-0.1379	-0.1246	0.3082	-0.4783
15	-0.2405	-0.0990	-0.1367	-0.0748	0.0044
16	0.0281	0.0332	0.3154	0.1958	-0.0041