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Rating and valuation of human haptic sensation

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Abstract. This paper is a study on development of a sensor system for measurement and valuation of human touch feeling. The objects measured are underwear, knitwear, sample underwear and polo shirts with total 26 sheets. First, the tactile feelings of several fabrics were/touch valued by using the paired comparison semantic differential method handed onto 5 subjects. Next, a soft tactile sensor made of a PVDF (Polyvinylidene Fluoride) file patch and rubber layers is assembled and slid over the same sample fabrics to collect the surface tactile information. The features on the collected data are then extracted by calculating the variance of output signal and the intensity of power spectrum density on medium frequency range. Comparison of the results shows that the PVDF sensor well describes the human touch feeling.

Keywords: Human haptic sensation, PVDF film, measurement, signal processing

1. Introduction

Touch is the most frequently used action to gather the information outside the body. In our daily life, various kinds of things are touched by fingers and their physical as well as morphological features are extracted and evaluated unconsciously. Thus, the sense of touch is indispensable to our life as is the sense of sight. In the tactile function, the digital pulp of finger is pressed against the object, and then the stroke/rubbing action is started over the surface of the object to feel the texture. It seems that most of the force sensors developed so far have been functional to the measurement of just force magnitude [1], while a few sensors are available for the rating of the texture on the object material.

It is well known that the current output from the polyvinylidene fluoride(PVDF) film is proportional to the rate of the strain induced in the film. Experimental results show that the output signal from the piezopolymer film takes the form of a brief potential wave at the onset of the pressure pulse and a similar brief wave at the termination. Further, there is no response during the stationary plateau of the applied pressure. The time variation is quite similar to the signal variation of the Pacinian corpuscle which is a sensory receptor in the dermis particularly functional to the touch-vibration of 250–300 Hz [2].

It is rather difficult to handle and/or measure thin fabrics since they are very flexible. The texture of fabrics has been conventionally described by using the terminology of hand as the occupation expert uses. It is characterized by the descriptive words like “body”, “compliant” and others. Recently, the present authors have assembled a tactile sensor made of PVDF films and soft rubber layers and measured the output current signals from the polymer films by sliding the sensor over the fabrics with different

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Table 1
Physical properties of fabrics

(*a*) *Underwear*							
	A	B	C	D	E	F	
MMD	1.08	0.45	0.65	0.48	1.44	1.19	
EMC	55	15.9	37.4	38.5	50	48.7	
(*b*)*Sample underwear*							
	A	B	C	D	E	F	
MMD	0.36	0.42	0.97	0.45	0.40	0.43	
EMC	31.6	35.1	32.5	45.8	41.8	43	
(*c*)*Knitwear*							
	A	B	C	D	E	F	G
MMD	0.47	0.54	0.42	0.53	0.54	0.43	0.37
EMC	23.7	18.4	7.7	18.5	20.5	12.1	18.5
(*d*)*Polo shirt*							
	A	B	C	D	E	F	G
MMD	0.97	0.64	0.72	1.14	0.97	0.71	0.73
EMC	30	34.8	37	27.4	34.9	41.6	38.8

Table 2
Evaluation on fabrics

(*a*) *Underwear*							
	A	B	C	D	E	F	
Good feeling	0.3	0.2	−0.3	0.1	−0.4	0.1	
Comfortable	0.4	0.1	−0.6	0.1	−0.3	0.3	
(*b*) *Sample underwear*							
	A	B	C	D	E	F	
Good feeling	0	0.3	−0.5	2	1.4	1	
Comfortable	−0.1	0.1	−0.3	2	1.6	1.1	
(*c*) *Knitwear*							
	A	B	C	D	E	F	G
Good feeling	−0.6	−1.1	0.5	−1.1	−0.3	−0.4	−1.2
Comfortable	−0.2	−0.7	0.6	−1	−0.3	−0.4	−0.6
(*d*) *Polo shirt*							
	A	B	C	D	E	F	G
Good feeling	0	0	0	−1.2	−0.6	0.6	0.6
Comfortable	0.2	0.2	0.6	−1.2	−0.2	0.2	0.4

texture. It was verified that the piezopolymer sensor extracts the features on the feeling of touch of the fabrics and holds the potential to be used as a haptic sensor [3]. Furthermore, through the experiment on the underwear, the power intensity in mid-frequency rage of sensor output were found to have clear correlation with the feelings of “good” and “comfortable” [4].

This paper is a study on the measurement and valuation of touch sensation on the texture of various kinds of fabrics. The human haptic feelings on several fabrics are compared with the output of piezopolymer sensor. The objects measured are underwear, knitwear, sample underwear and polo shirts with total 26 sheets. First, the objective specific feelings are collected on several fabrics through the questionnaires based on the paired comparison semantic differential method. Next, the soft tactile sensor is slid over the same fabrics to collect the surface tactile information. The features on each fabric are extracted through the processing of the collected data. Comparisons with the results show that the active sensing using the PVDF piezosensor can be a substitution for the human tactile function.

Table 3
Experimental Conditions

Applied force to object	6.3×10^{-2} (N),
Scanning speed of sensor	160 (mm/sec)
Measuring time	100 (msec)
Sampling time	0.2 (msec)
Direction of scanning over object surface	Up to down direction of body

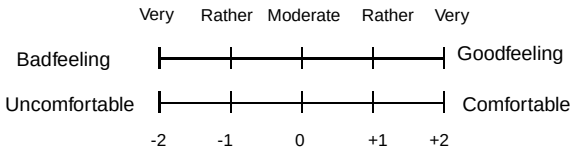

Fig. 1. Questionnaires of wearing/touching fabrics.

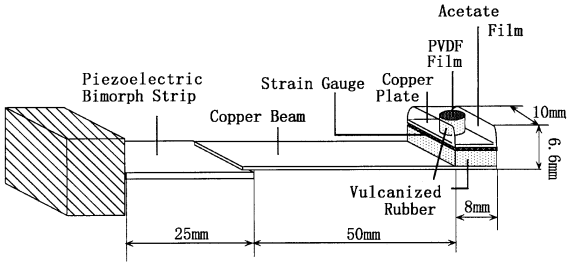

Fig. 2. Geometry of sensor system.

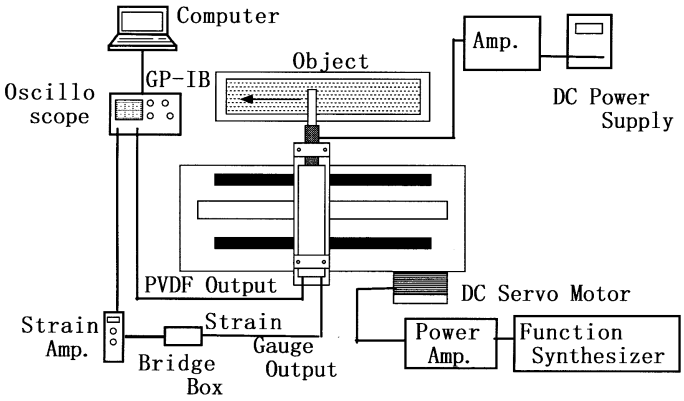

Fig. 3. Experimental setup.

2. Measurement of human tactile sensations

The human wear/touch sensation was examined by using 4 kinds of fabrics. They are underwear (6 pieces), knitwear (7 pieces), sample underwear (6 pieces) and polo shirts (7pieces), with total 26 sheets. Each test was carried out by 5 examinees. Table 1 shows the characteristics of the sample fabrics. MMD and EMC denote the mean deviation of the coefficient of friction and the compressibility, respectively. The subjects were requested to present their feelings of wear and touch and the overall feeling was determined through the questionnaire based on the paired comparison SD (semantic differential) method. The examination was done in the environment of 24.5 degrees C and 55%RH (relative humidity). Figure 1 is the questionnaire handed onto the subjects. Each feeling is subdivided into a five –step scale from left to right with the rate of –2 through 2 allotted to each step. The feelings on the quality of wear/touch were valued by calculating the weighted mean on the 5 data presented by the subjects. The results are given in Table 2. Samples with the highest of “good feeling” have also the highest rate of “comfortable”.

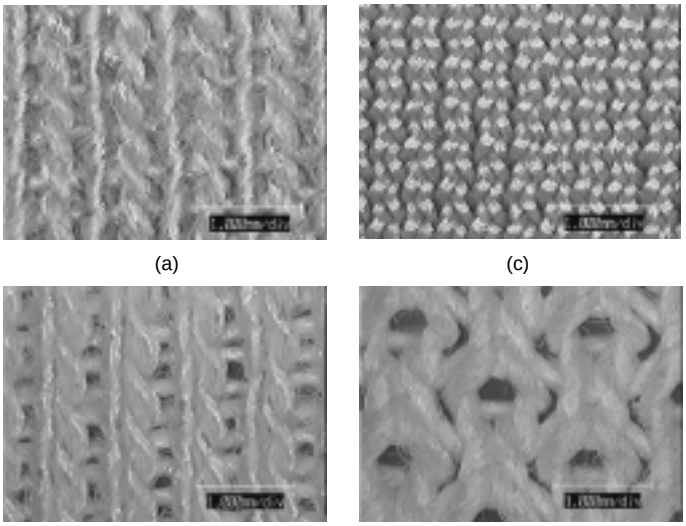

Fig. 4. Typical surface of fabrics observed with a microscope. (a) underwear, (b) sample underwear, (c) knitwear and (d) Polo shirt.

3. Tactile sensor and experimental setup

Figures 2 and 3 present the structure of the sensory system and experimental setup, respectively. The tactile sensor is an assembly of layered media. The base of the sensor is copper plate, on which a vulcanized rubber block, a polyvinylidene fluoride (PVDF) film as the sensory receptor, and a protective surface layer of acetate film are stacked in sequence. The PVDF sensor was mounted on a slider, which is driven by a DC servomotor and a belt and slid over a target object with a constant speed. The piezoelectric bimorph strip was used to apply a constant load to the sample object. The input voltage to the actuator was set at 25 V which correspond to the applied force to the object at 0.05 N. The measured side was the back of the fabrics since the contact surface to human body is backside. The sliding direction is vertical direction of body. Details on the experimental conditions are presented in Table 3.

4. Signal processing

In this study, the ratio of the power in mid-frequency to the power over mid-high frequency range, Rs, was used as an index to extract the feature of the collected data. The power ratio Rs is defined as follows.

$$RS = \frac{S_a}{S_b}@, S_a = \sum_{n=f_1}^{f_2} P(f), S_b = \sum_{n=f_1}^{f_3} P(f), \quad f_1 = 100 \text{ Hz}, f_2 = 500 \text{ Hz}, f_3 = 2000 \text{ Hz}. \tag{1}$$

Here, $P(f)$ denotes the power spectrum density.

As the second index, the variance of the output of sensor, V was calculated. The variance V is defined as follows.

$$v = \frac{N\sum_{i=1}^{N} x(i)^2 - \left(\sum_{i=1}^{N} x(i)\right)^2}{N(N-1)} \tag{2}$$

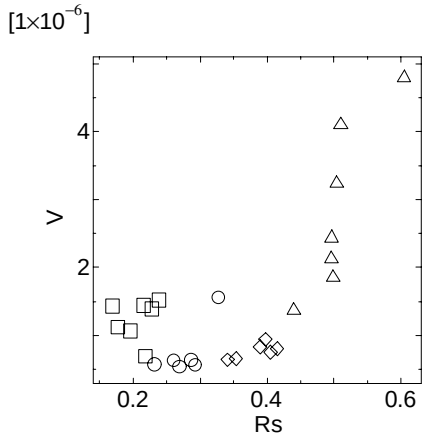

Fig. 5. V vs. Rs on four fabrics (◯: Underwear, ◇: Sample Underwear, □: Knitwear and △: Polo Shirt).

Table 4
Rs and V

(i) Underwear			(ii)Sample underwear		
	Rs	V		Rs	V
A	0.406	5.33E-07	A	0.353	5.48E-06
B	0.594	9.06E-07	B	0.435	5.83E-06
C	0.767	1.52E-06	C	0.445	8.41E-06
D	0.608	7.59E-07	D	0.267	6.30E-06
E	0.440	6.13E-07	E	0.264	6.15E-06
F	0.412	4.4E-07	F	0.329	6.89E-06
(iii)Knitwear			(iv)Polo shirts		
	Rs	V		Rs	V
A	0.239	5.19E-06	A	0.448	1.71E-05
B	0.334	6.76E-06	B	0.381	1.26E-05
C	0.251	7.74E-06	C	0.382	1.32E-05
D	0.292	4.82E-06	D	0.367	1.29E-05
E	0.285	6.38E-06	E	0.352	1.28E-05
F	0.266	3.98E-06	F	0.331	1.27E-05
G	0.238	3.62E-06	G	0.352	1.30E-05

Here, $x(i)$ is the i-th quantitized digital signal and N is the total number of digital signals.

Measurement was done 5 times on each sample and the average values of two indexes were calculated. Further, the obtained average values are compared with the touch feelings give in Table 2.

5. Results and discussions

The two indexes of Rs and V obtained through the experiment are presented in Table 4. As I have mentioned before, through the experiment on the underwear, the power intensity in mid-frequency range of sensor output Rs were found to have clear correlation with the feelings of "good" and "comfortable" [4]. In this study, various kinds of fabrics are used as the measurement samples. In order to investigate the correlation of the feelings with sensor output, the correlation coefficients are calculated. The correlation

Table 5
Correlation of volunteers' rating "good feeling" and "comfortable" with sensor output Rs

	Underwear	Sample Underwear	Knitwear	Polo Shirt
Good feeling	−0.778	−0.882	−0.327	−0.123
Comfortable	−0.72	−0.900	−0.479	0.1238

Table 6
Rs and V (improved sensor)

	(i)Underwear		(ii)Sample underwear		
	Rs	V		Rs	V
A	0.232	5.68E-07	A	0.390	8.30E-07
B	0.270	5.35E-07	B	0.415	8.04E-07
C	0.287	6.37E-07	C	0.397	9.44E-07
D	0.261	6.29E-07	D	0.341	6.44E-07
E	0.328	1.55E-06	E	0.353	6.61E-07
F	0.293	5.59E-07	F	0.405	7.50E-07
	(iii)Knitwear		(iv)Polo shirts		
	Rs	V		Rs	V
A	0.177	1.12E-06	A	0.496	2.13E-06
B	0.216	1.44E-06	B	0.499	1.85E-06
C	0.169	1.43E-06	C	0.504	3.24E-06
D	0.228	1.39E-06	D	0.604	4.79E-06
E	0.238	1.52E-06	E	0.510	4.10E-06
F	0.196	1.06E-06	F	0.440	1.37E-06
G	0.218	6.97E-07	G	0.496	2.44E-06

coefficient defined by

$$r = \frac{\sum_{i=1}^{m}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{m}(x_i - \overline{x}^2 \sum_{i=1}^{m}(y_i - \overline{y})^2}} \tag{3}$$

is introduced and calculated. Here, x_i is the valuations of touch feelings of fabric i, either feelings of "good" or "comfortable", and y_i is the sensor output Rs, and $\overline{x}$ and $\overline{y}$ are the mean of x_i and y_i, respectively. The number of measurement object is denoted by m. At the case of underwear, the number was set at $m = 6$. Similarly, when the sample is knitwear, sample underwear and polo shirts, m corresponds to 7, 6, and 7, respectively. The correlation coefficients calculated on the valuations of Table 2 and sensor output Rs of Table 4 are presented in Table 5. In Table 5, it is seen that the feelings "good", and "comfortable" of underwear have a clear correlation with Rs, while, it is not clear for polo shirts. To examine the reason, the reticulation of the fabric was examined. Typical surfaces of fabrics observed with a microscope are presented in Fig. 4. It is seen to be vertical except for the polo shirts. The direction was diagonal for the polo shirts. The gauze was then introduced to the surface of the sensor to make the sensor scanning omni directional. Table 6 shows the sensor output of Rs and V, which were obtained by using the improved sensor. Table 7 shows the relation of the volunteers' rating "good feeling" and "comfortable" with Rs. It is seen that the feelings of all samples have correlation with Rs.

Next, the distribution of Rs and V were investigated. Figure 5 shows the result. From this, the 4 kinds of fabrics are discriminated clearly using these values of Rs and V.

The results given above lead to a conclusion that the intensity of power in the mid-frequency range again has definite correlation with the contact feelings of "good feeling" and "comfortable". Further,

Table 7
Correlation of volunteers' rating "good feeling" and "comfortable" with sensor output Rs. (improved sensor)

	Underwear	Sample Underwear	Knitwear	Polo Shirt
Good feeling	-0.598	-0.778	-0.732	-0.810
Comfortable	-0.835	-0.746	-0.592	-0.880

the relation of sensor variance V and intensity of power in the mid-frequency range Rs are possible to discriminate the fabrics.

6. Conclusions

An experimental study has been presented on the measurement and valuation of human touch sensations. The human tactile perception has been compared with the output of PVDF piezopolymer sensor output. The obtained results are summarized as follows.

(1) Human tactile feelings on the wear/touch of underwear, knitwear, sample underwear and polo shirts were measured by using the questionnaire based on the paired comparison semantic differential method. The feelings were then valued numerically.
(2) The variance of the output of sensor and the power intensity in mid-frequency range of all of fabrics were found to have clear correlation with several specific feelings of wear/touch. Further, several kinds of fabrics are discriminated by the sensor output.

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