Tactile Presentation Scheme Based on Physiological Characteristics of the Fingertip

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Abstract. In the case of the product purchase decision making in e-commerce, the tactile sensation a user can obtain from products is restricted. Our goal is to construct a framework for tactile measurement and presentation to remove such restrictions. To realize high-accuracy tactile presentation, we analyze the mechanical characteristics of the fingertip. We measured and analyzed the interactional force of the contact face when stroking the surface of fabrics. We found a filter-bank like structure of vibration information processing on the fingertip. In addition, we propose a tactile presentation scheme based on this physiological characteristic. To evaluate the validity of the proposed scheme, we produced a tactile presentation device for fabrics and evaluated the reproducibility of tactile sensation. The results demonstrate that it is possible to represent basic material texture characteristics, such as roughness and softness. This study provides key technological knowledge for constructing a framework for tactile measurement and presentation. Furthermore, this study promotes the use of sensory information relative to tactile sensation in e-commerce, such as the visual and auditory senses.

Keywords: Tactile presentation · Biomechanical analysis · Fingertip

1 Introduction

Recently, diversification of user needs has occurred with the globalization of the market environment accompanied by the spread of e-commerce [1]. In consideration of product purchase decision making in e-commerce, the sensory information a user can obtain from products is restricted. Despite the fact that tactile sensation is important information relative to the value of a product, there is no existing framework for measurement and presentation.

Tactile presentation using vibration is effective when mounting on a small communication device, such as a smartphone [2]. In particular, a DC motor reproduces vibrations in a wide frequency band as flat [3]. The vibrations sensed by mechanoreceptors that have different frequency characteristics [4]. However, presenting vibration using a DC motor makes it impossible to independently control vibration, which corresponds to the frequency characteristics of the mechano-receptor. Moreover, it is unclear how to realize tactile presentation using a DC motor.

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In this study, we demonstrate the vibration features of an interactional force occurring while stroking a surface texture with a fingertip. We propose a physiological characteristics-based construction scheme for tactile presentation that is realized using multiple vibrators. Based on the proposed construction scheme, we realize the tactile presentation of fabrics, which is desirable in the e-commerce field. We also evaluate the validity of the tactile presentation.

2 Mechanical Information Processing of Fingertip

We developed a specialized device [5] to measure contact force that occurs on the contact surface between the fingertip and surface texture during a stroking movement (Fig. 1). This device simultaneously measures frictional (horizontal) force and press (vertical) force while stroking an object's surface. To clear the vibration characteristics of the fingertip, we measured and analyzed interactional force when stroking the surface of fabrics.

2.1 Participants

Twenty healthy college and graduate students (15 males and five females; 22.2 $\pm$ 0.97 years)

2.2 Materials

Thirteen fabrics (Fig. 2) were included in a texture sample set provided by Takei Scientific Instruments Co. Ltd.

2.3 Frequency Analysis

First, we performed frequency analysis of the measured data using Welch's method to obtain the frequency characteristics of each fabric (Fig. 3). Note that differences in spectrum contribute to the formation of tactile sensation for each fabric.

To represent the difference as features, principal component analysis was applied to the entire spectrum set. We found that the vibration of the contact force can be expressed as a multichannel filter bank-like structure in time-frequency space (Fig. 4).

The power of the frequency corresponding to each of the six bases was obtained as the feature value. The differences between the samples of these features were visualized using multi-dimensional scaling (Fig. 5). We confirmed that the features provide sufficient information to represent differences in tactile sensations.

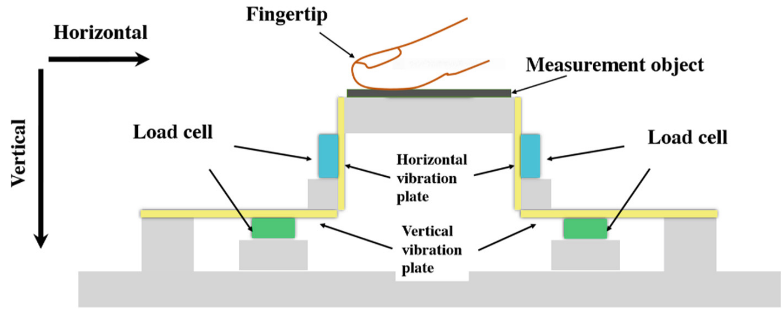

Fig. 1. Schematic of measurement device

Fig. 2. Fabric samples

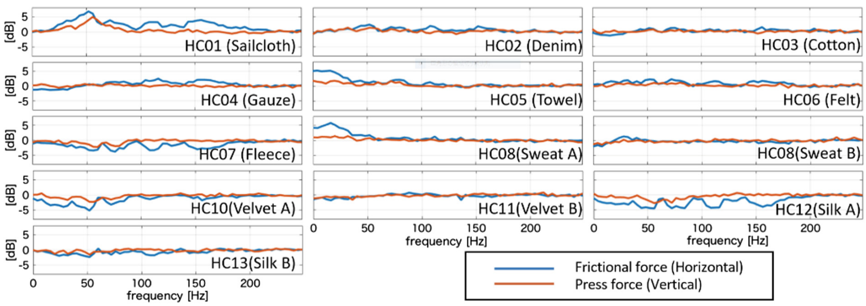

Fig. 3. Frequency characteristics of interactional force vibration

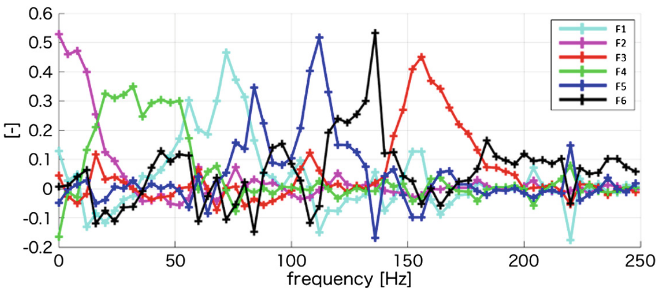

Fig. 4. Plot of the basis set of PCA (six components) of the frictional force of fingertip when stroking fabrics

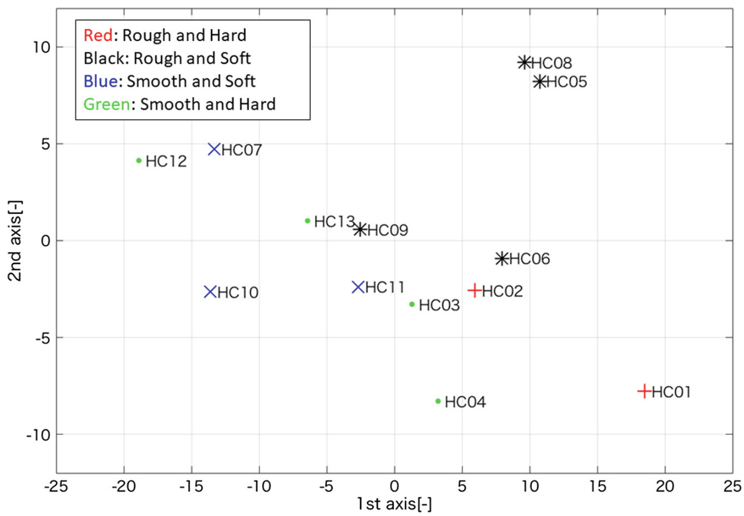

Fig. 5. Distribution of fabric samples in six-dimensional feature space

3 Tactile Presentation Scheme Based on Vibration Characteristics of Fingertip

3.1 Basic Concept

The result shown in Fig. 4 suggests that vibration during stroking can be represented using a number of vibrators that correspond to the passing frequencies of the bandpass filters that comprise the filter bank.

This makes it possible to control tactile presentation performance relative to the number of vibrators because the contact force is the primary information comprising tactile sensation, and the reproduction accuracy of the vibration corresponds to tactile presentation performance.

In this study, we developed a tactile presentation device based on the vibration characteristics of the fingertip (Fig. 6).

3.2 Implementation

To control each element of the features independently using a DC motor, the control parameters (motor type, voltage, and duty ratio) of the pulse wave modulation were searched comprehensively. As a result, we were able to present each element of the features with two intensity levels, except for a part (Table 1). The control parameters were determined from the difference of features with H12 for four samples (H01, H02, H05, and H12) with different features, as shown in Fig. 5 (Table 2). Thus, the standard material used the silk-like fabric, which provides the same tactile sensation as H12.

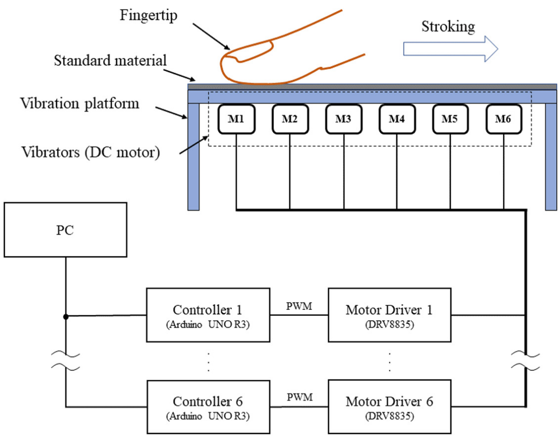

Fig. 6. Schematic of tactile presentation device based on proposed presentation scheme

Table 1. Enhancement intensity of the element of features using DC motor.

Motor ID	Vibration Intensity	Degree of Enhancement					
		F1 (56–80Hz)	F2 (0–16Hz)	F3 (144–180Hz)	F4 (20–52Hz)	F5 (84–116Hz)	F6 (120–140Hz)
M1	High	34.7	−5.1	2.6	4.0	−4.6	−9.4
	Low	12.0	−0.7	−5.7	3.2	−14.5	−4.3
M2	High	−10.2	30.9	1.6	−5.4	8.4	38.1
	Low	−5.2	20.2	−2.1	−0.2	17.4	37.8
M3	High	4.8	0.6	25.7	−3.0	−2.9	12.0
	Low	3.0	−0.7	13.4	−1.4	1.7	0.4
M4	High	−0.4	0.3	−2.4	9.2	−2.3	5.3
	Low	–	–	–	–	–	–
M5	High	−5.5	−1.3	12.6	1.7	41.4	11.1
	Low	−1.8	4.3	8.1	6.2	28.1	8.1
M6	High	2.7	0.9	−4.1	−2.3	9.4	21.9
	Low	−6.6	1.6	2.3	−1.9	4.0	9.7

Table 2. Control state of each experimental sample.

Stimuli	Control state					
	M2 (0–16 Hz)	M4 (20–52 Hz)	M1 (56–80 Hz)	M5 (84–116 Hz)	M6 (120–140 Hz)	M3 (144–180 Hz)
HC01 (Sailcloth)	Off	High	High	High	High	High
HC03 (Cotton)	Off	High	Low	Low	Low	Low
HC05 (Towel)	High	High	Low	Low	Off	Low
HC12 (Silk A)	Off	Off	Off	Off	Off	Off

4 Evaluation of Proposed Scheme

To evaluate the capability of the proposed tactile presentation scheme, we performed a subjective evaluation of each of the presented tactile sensations and the tactile sensation obtained from real fabrics. We also evaluated the similarity between these tactile sensations.

4.1 Participants

Four healthy college and graduate students (two males and two females; 23 ± 1.4 years) participated in this evaluation.

4.2 Materials

Four fabrics were evaluated (Table 2).

4.3 Experiment 1: Subjective Evaluation

Procedure
The participants sensed the tactile perception from the tactile presentation device and performed a 5-point Likert scale evaluation of 12 tactile impression words for each sample. Then, the participants stroked the real fabric surface and evaluated the tactile impression words.

Results
To evaluate the effect of vibration presentation, we demonstrated the differences in the evaluation values relative to the reference samples, e.g., H12 and the standard material (Fig. 7). The vertical axis is the amount of change from the evaluation value relative to the reference sample (e.g., H12 and standard material). The results indicate that the produced tactile presentation can reproduce the differences in tactile sensations for different samples.

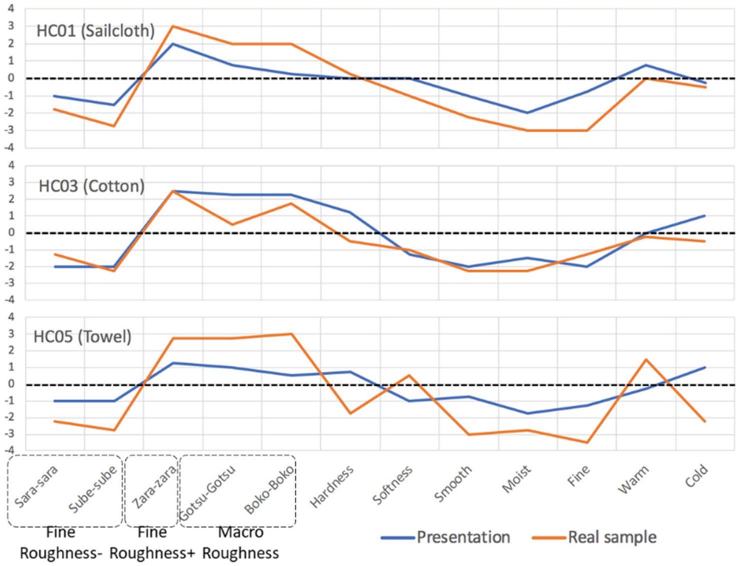

Fig. 7. Reproducibility of tactile sensation relative to the 12 tactile impression words

4.4 Experiment 2: Similarity Evaluation

Procedure

First, the participants sensed the tactile perception from the tactile presentation device. Then, the participants selected a sample similar to the presented perception from four fabric samples.

Results

We confirmed that the presentation device could present the tactile perception of HC02 (cotton) with good accuracy (Table 3). Note that HC01 (sailcloth) was evaluated as HC02 (cotton) with less roughness than HC01 (sailcloth). Although the unevenness of the surface of HC01 (sailcloth) is large, the standard material has a flat surface. We believe that this result was caused by the strong perception of this difference in the surface condition.

Although the surfaces of HC01 (sailcloth) and HC05 (towel) have the same degree of unevenness, the concordance rate was relatively high. HC05 (towel) is a soft material, and the surface structure deforms when stroked, which suggests that deformation can be expressed by vibration.

Note that M2 could not selectively control the feature amount of F2 and may have contributed to the reduction in concordance rate. This was due to the motor structure. In addition, the motor type and control method must be considered to realize tactile presentation with higher accuracy.

Table 3. Evaluation of similarity between presented tactile and actual tactile sensations.

		Selection				rate of concordance
		HC01	HC02	HC05	HC12	
Presentation	HC01	0	3	1	0	0%
	HC02	0	3	1	0	75%
	HC05	2	0	2	0	50%
	HC12	0	0	0	4	100%

5 Conclusions

We have demonstrated the filter-bank-like structure of vibration information processing on the fingertip. In addition, we have proposed a physiological characteristics-based construction method for tactile presentation. To evaluate the availability of the proposed method, we produced a tactile representation device for fabrics. Evaluation results indicate that it is possible to represent basic material texture, e.g., roughness and softness. As a result, we confirmed the validity of the proposed method.

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