Investigation of Method Presented Nonverbal Information Using Tactile Sensations of Real Objects

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***Abstract*—The objective of this study is to aid visually impaired people by presenting them with nonverbal information regarding aspects such as the atmosphere, object state, and facial expressions through the incorporation of tactile sensations of real objects. Such information is often helpful in stimulating one's imagination and in comprehending or predicting a situation without using words, and it comprises multiple elements such as emotions, motions, and relationships among objects. Furthermore, it is difficult to express such information by employing a single scale, and it is thus necessary to present multiple elements. In this context, the sense of touch can be employed for simultaneously presenting multiple elements and reading tactile sensations. In this study, tactile sensations of objects were utilized for presenting nonverbal information. A prototype system was developed for combining tactile sensations associated with softness, smoothness, and flatness. This study also investigated the number and variety of tactile sensations presented by the proposed system that could be recognized by sighted people. The obtained results indicate that approximately 80% of the people can recognize the sensation of smoothness presented by the system, and more than 50% of the people can recognize the sensations of softness and flatness.**

***Keywords*-Nonverbal Information; Tactile Sense; Information Presentation**

I. Introduction

There are many visually impaired people around the world and they often face difficulties with accessing sufficient visual information in their daily lives by the condition. To supplement their visual information, methods of presenting information utilizing the sense of touch are pervasive, and braille is one such method. Visually impaired people can obtain character information that is usually visually presented by tracing and reading braille for themselves.

Visual information contains not only linguistic information (such as character information) but also nonverbal information that sighted people do not verbalize, even though they see and recognize it. Nonverbal information includes color, facial expression, movement, appearance, atmosphere, and texture. This information is useful for sighted people because they can utilize this information when imaging, understanding, predicting, and judging a situation. However, visually impaired people cannot access nonverbal information, so methods to present this information to them are scarce.

The goal of this research is to present nonverbal information to visually impaired people. Nonverbal information is composed of multiple elements, such as emotion, movement, and the relationships between objects. To express the information, using one scale only is difficult, thus presenting multiple elements is necessary.

The sense of touch is one method that can present multiple elements and can perceive tactile sensations, however, the current method such as braille only provides a limited type of information and it is difficult to convey the various types of non-verbal information simultaneously. To solve the problem, this paper proposes that nonverbal information can be presented by tactile sensations of objects without visual information. As a starting point, we developed a prototype system to combine the tactile sensations of softness, smoothness, and flatness simultaneously. This study investigates whether people can recognize the type and number of tactile sensations presented by the system.

II. Related Works

Research on the presentation of nonverbal information that utilizes the sense of touch to enrich the lives of visually impaired people has been conducted. Ueda *et al.* developed a small tactile display called TAJODA [7]. It can present some characteristics of text, such as text size, thickness, and blank lines, when visually impaired people use the function reading character with a computer. TAJODA uses 16 tactile transducers to present information to the fingertips. Using TAJODA, people can perceive important information about bold font and other types of text while listening to text on their computer.

Asakawa developed a device that transmits the movement of a conductor's baton using the sense of touch so that visually impaired people can enjoy a chorus with sighted people [1]. The device can transmit vibration according to the rhythm specified by the conductor.

Sagawa *et al.* focused on the color information of clothes and developed a tactile tag that presents color using an arrangement of hue circles [6]. Using this tag, visually impaired people can enjoy colors that cannot be seen.

Other studies on tactile sensation have been conducted. When touching an object, a person recognizes its shape and texture, and texture is recognized faster than shape. Using the characteristic of texture, Harrison *et al.* studied the possibility of an interface that changes the tactile sensation of texture [2]. They performed experiments to determine whether people could distinguish the deformed material by expanding and contracting six types of material, such as spandex and a beaded matrix. As a result, although there was a difference in the correct answer for each material, it was shown that a person could recognize the state of the material based on its tactile sensation.

III. System requirements

This section describes the tactile sensations presented by the proposed system. Tactile sensation is based on three aspects: physical, material, and mental [3].

A. Physical aspects

The physical aspects of tactile sensations include the body movements made when people touch an object and the audio-visual and tactile information received by sensory organs. The purpose of this research is to present nonverbal information using only the sense of touch, so this research focuses on movements that occur when people touch an object. Such movements are broadly classified as passive touch and active touch. Passive touch occurs when a user receives a stimulus without moving his or her fingers or hands. Active touch occurs when the user receives a stimulus by moving his or her fingers and hands in an exploratory manner. Nishimatsu *et al.* investigated the superiority of passive and active touch in the material discrimination of samples [4]. Their results revealed that active touch helps the user distinguish the material better than passive touch.

In addition, if a user continues to receive the same stimulus, he or she becomes less responsive, and this phenomenon is called adaptation. In adaptation, a user continues to rest his or her hands and becomes less responsive. To avoid a decrease in responsiveness, it is necessary to continuously present a stimulus to the fingers, for example, by moving and pressing them or repeated touches. These movements are examples of active touch, which is suitable for recognizing tactile sensations. In this study, it is assumed that people use active touch when they touch the prototype system.

B. Material aspects

The material aspects of tactile sensations include the texture of objects, material characteristics, and state of the objects (e.g., vibration or stillness). There are many studies on material characteristics; however, the samples used in this research vary from study to study. As a result, the material features that are assumed to compose the material appearance are also diverse. To extract the material features of tactile texture, Nagano *et al.* compared several studies on material characteristics. They concluded the material features consist of five main dimensions: fine-roughness–smoothness, hardness–softness, coldness–warmness, macro-roughness, and friction (e.g., moist–dry and sticky–slippery) [5]. These dimensions can be used as elements to create tactile sensations for presenting nonverbal information.

Active touch, which is assumed in this study, has more transformation about softness and is superior for recognizing softness, smoothness, and flatness than passive touch [4]. Hence, the material dimensions presented by the prototype system are softness, smoothness, and flatness.

C. Mental aspects

The mental aspects of tactile sensations are composed of memory, past experience, and language (e.g., onomatopoeias). Nakatani *et al.* noted that if a tactile image can be evoked using language and memory, tactile sensation can occur without the physical and material aspects [3]. However, language and memory differ from person to person and are difficult to understand. Hence, this study does not consider the mental aspects.

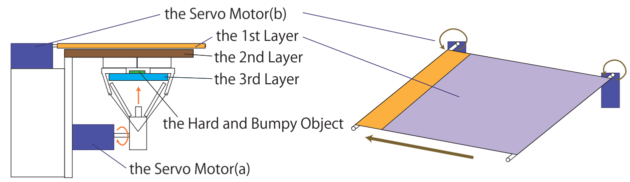

Figure 1. A Prototype System

IV. Implementation

The prototype system consists of a component made by three-dimensional printer, a 180-degree rotating micro-servo motor (a) and a 360-degree continuous rotating micro-servo motor (b), an Arduino Uno R3, a hard and bumpy object, and clothes.

The component is 90 *mm* square with a 40 *mm* square hole at the center. To open and close this hole, a shutter is attached to the component. Furthermore, a 35 *mm* square plate is suspended from this component. The component, plate, and cloth are layered (see Figure 1). Each layer plays a different role. The cloth forms the first layer and displays smoothness to the user, the component forms the second layer and displays softness, and the plate forms the third layer and displays softness and flatness.

A. Presentation of the tactile sensations

To present softness, the second layer with soft cotton and the third layer with a hard and convex object are used. The

Table I
EIGHT PATTERN PRESENTED BY SYSTEM

	Softness	Smoothness	Flatness	Types of bump
①	Soft	Smooth	Flat	
②	Soft	Smooth	Bumpy	Cloth
③	Hard	Smooth	Bumpy	Object
④	Hard	Smooth	Bumpy	Cloth & Object
⑤	Soft	Rough	Flat	
⑥	Soft	Rough	Bumpy	Cloth
⑦	Hard	Rough	Bumpy	Object
⑧	Hard	Rough	Bumpy	Cloth & Object

state in which the user can touch only the second layer and cannot touch the third layer displays softness. While in the soft state, servo motor a rotates and pushes up the third layer. This state displays hardness to the user.

To present smoothness, the first layer is used. The cloth used in the first layer has smooth and rough sections that are is switched to present the smooth or rough states. A cloth is wrapped around rollers installed on the left and right sides of the system, and these rollers rotate at the same time as servo motor (b), thereby switching the type of cloth.

To present flatness, the first layer and the third layer with the hard and convex are used. The cloth has two types of surface: flat and little bumpy. The object is an object in which some cylinders with a diameter of 1.8 *mm* and a length of 1.5 *mm* are arranged at 2.0 *mm* intervals. When the bumpy part of the cloth is used for the first layer, or when the object is placed on the third layer and pushed up, bumpiness is displayed. When a flat cloth is used for the first layer, or when the third layer is pulled down, flatness is displayed.

In this way, eight patterns of tactile sensation are presented by combining softness, smoothness, and flatness (see Table I).

V. EXPERIMENT

To evaluate the differences between the tactile sensations presented by the prototype system and the tactile sensations users perceive, experiments were conducted using 16 students from the School of Informatics.

A. Experimental procedure

The subjects first touched all eight patterns with their dominant hand for 10 seconds with their eyes closed. Then, all the patterns were touched in random order for the evaluation. No time limit was imposed at this stage so that the tactile sensations could be understood correctly. To avoid influence from the pattern presented immediately before, the participants in the experiment traced a paper three times with their dominant hand each time the presented pattern was changed.

The tactile sensation was evaluated on a 5-point Likert scale for five items using a questionnaire. The five items, which are based on the dimensions of the object's material texture, are "rough–smooth," "dry–wet," "warm–cool," "soft–hard," and "flat—bumpy." A description field was provided at the end of the evaluation questionnaire so that the subjects could describe their impressions of the system.

Table II
THE AVERAGE VALUE OF THE TACTILE EVALUATION

	①	②	③	④	⑤	⑥	⑦	⑧
Softness	1.2	1.3	2.0	1.8	3.5	3.5	3.5	3.9
Smoothness	4.8	3.4	4.6	3.4	2.3	1.6	2.5	1.5
Flatness	2.1	3.1	2.1	3.6	2.4	4.5	2.5	4.3
Dryness	2.9	3.1	3.2	2.6	2.0	2.1	2.0	1.8
Warmness	3.1	3.0	3.2	2.8	3.1	3.0	3.0	2.7

B. Results

The five options in the evaluation questionnaire were treated as numerical values. For instance, for "rough–smooth," 1 is very rough, 2 is a little rough, 3 is neither rough nor smooth, 4 is a little smooth, and 5 is very smooth; the other items such as "dry–wet" were similarly processed. The average values of the tactile evaluations of the experiment participants are shown in Table II. It is assumed in the evaluation that perceptions described as "very" and "a little" both match the tactile sensations presented by the system. The match rates were then calculated.

The match rate of the presentation of softness in all patterns is 54.3%, and the match rates of the hard and soft states are 44.4% and 64.0%, respectively. The match rate of the presentation of smoothness is 80.3%, and the match rates of the rough and smooth states are 82.8% and 77.7%, respectively. The match rate for the presentation of flatness is 59.8%, and the match rates of the flat and bumpy states are 65.6% and 57.8%, respectively. There are three types of flatness display: one using cloth, one using a bumpy object, and one using a combination of cloth and bumpy object. The match rates for each type are 68.7%, 31.2%, and 74.1%, respectively.

Table III shows the match rates of softness, smoothness, and flatness for each presentation pattern.

The match rate and average value are obtained by rounding down the second decimal place. In the presentation of softness, the average value of patterns ⑤ – ⑧ is about 3.5, which is an evaluation of neither hard nor soft. However, the match rate of patterns ⑦ and ⑧ is 65% or more, which indicates that a somewhat appropriate evaluation was performed for each of the presentation of the hard and soft states over a certain level.

In the presentation of smoothness, the match rate was 65% or more for all patterns except for pattern ②. In the presentation of flatness, the average value indicates that the evaluation was flat for many patterns. There is variation in the match rate according to each pattern.

In the free text box provided in the questionnaire, the participants mentioned that the difficulties to distinguish

Table III
THE EVALUATION MATCH RATE OF THE PRESENTATION

	①	②	③	④	⑤	⑥	⑦	⑧
Softness	93.7%	100%	18.7%	13.3%	25.0%	37.5%	68.7%	75.0%
Smoothness	93.7%	50.0%	93.7%	73.3%	81.2%	87.5%	68.7%	93.7%
Flatness	75.0%	50.0%	18.7%	60.0%	56.2%	87.5%	43.7%	87.5%

between flatness and smoothness, and bumpiness and roughness.

VI. DISCUSSION

The average values of patterns ① – ④, which are the patterns using a smooth cloth, are at most 2.0, and the average values of patterns ⑤– ⑧, which are the patterns using a rough cloth, are at least 3.5 or more. This shows that the experiment participants perceived the softness of the cloth more than the softness of the hard object.

This is thought to be due to the movement that occurred when the experiment participants touched the system. The appropriate movement for perceiving softness is to push a hand or press a finger. However, many participants touched the system by stroking the surface. Therefore, the hard object in the third layer may not have been correctly perceived by the participants.

To present bumpiness, three methods of presentation were used: the cloth, the bumpy object, and a combination of the cloth and bumpy object. The results suggest that it is difficult to present only bumpy objects and that the display of a bumpy state using a combination of cloth and bumpy object conveys bumpiness most reliably.

The average values for the smoothness and flatness displays hardly distinguished the two types of roughness. However, for pattern ⑦, the value of smoothness was 2.5 and the value of flatness was 2.5. Here, the surface of the pattern was evaluated as rough and flat, indicating the possibility of separately presenting these two types of roughness.

The average values of the dry-–wet and warm–cold states are close to 3 for most of the presentation patterns. These values are appropriate because they are tactile sensations that the system does not present. However, the average value of some patterns are about 2 and their patterns were evaluated to be in a dry state. This shows there is the possibility of presenting a tactile sensation of dryness using a cloth without the need to install a new mechanism to present it.

One of the factors that made it difficult to distinguish between flatness and smoothness, and bumpiness and roughness is probably because the mental aspects was not taken into consideration. The words used for evaluation in the questionnaire were adjectives, but onomatopoeia may be able to distinguish the words. In the future, it is necessary to consider mental aspects.

VII. CONCLUSION

This study proposed a method for presenting nonverbal information utilizing the tactile sensations of objects without visual information and investigated whether users can recognize the type and number tactile sensations presented by a prototype system. The system combined the tactile sensations of softness, smoothness, and flatness for simultaneous display. The results of the experiment show that the system can present some tactile sensations. They also indicate that it is possible to present combined tactile sensations using the texture of an object without visual information.

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