Haptic Feeling Technologies for Surface Interaction

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Abstract
The current COVID19-related situation has demonstrated the importance of remote tactile transmission technologies. In this presentation, I will introduce some attempts to record and reproduce tactile feelings. A system that records the skin deformation when it touches rough surfaces and high-resolution tactile feeling displays are introduced.

1 Introduction

The presentation of tactile sensation has been attracting a lot of attention recently, especially in the field of remote communications. For such applications, haptic presentation needs to convey not only symbolic information but also high-definition tactile feeling, such as the haptic feeling of cloth and human skin.

On the other hand, presentation of tactile feeling is still limited, firstly due to the lack of hardware that can stimulate the fingertip with a higher temporal and spatial resolution than the skin can perceive, and secondly due to the lack of observation of real skin contact (Fig. 1). Tactile display can be regarded as a device to present distribution of skin deformation, so we need to know how the skin deforms, in both temporally and spatially.

In this paper, I will introduce two main research projects aimed at overcoming this situation. The first is the development of a skin deformation measurement device that achieves high temporal and spatial resolution. The second is the development of high-resolution tactile displays.

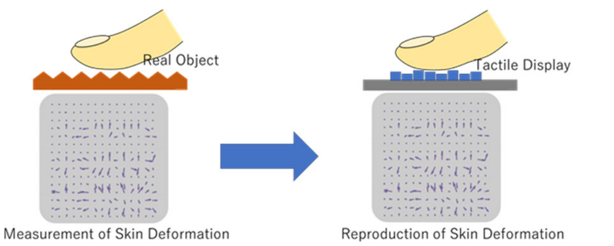

Fig. 1 Record and replay of tactile feeling.

2 Measurement of skin deformation

Many methods are used to observe tactile phenomena, such as force and vibration measurement by load-cells or accelerometers. On the other hand, direct measurement of skin deformation is desirable, which is typically achieved by capturing skin image through transparent objects. The finger contacts transparent plates, and the high-speed camera captures skin deformation. However, it required the transparent object to be flat or smooth to allow optical observation, and observation trough textured plate is impossible.

To enable optical observation even when the object has textures, we have developed an index matching method in which the measurement system is submerged in oil (Fig. 2)[1][2]. The oil has the same refractive index as that of the transparent object so that the boundary between the object and the oil is optically invisible, enabling direct observation of the skin.

Markers are applied to the finger in advance and are tracked by the camera. The finger is fixed and the contact object is driven by a linear actuator. This measurement system is capable of measuring the shear displacement of finger skin with an accuracy of less than 5 μm. The configuration of two cameras and a stereomicroscope enables us to capture depth information.

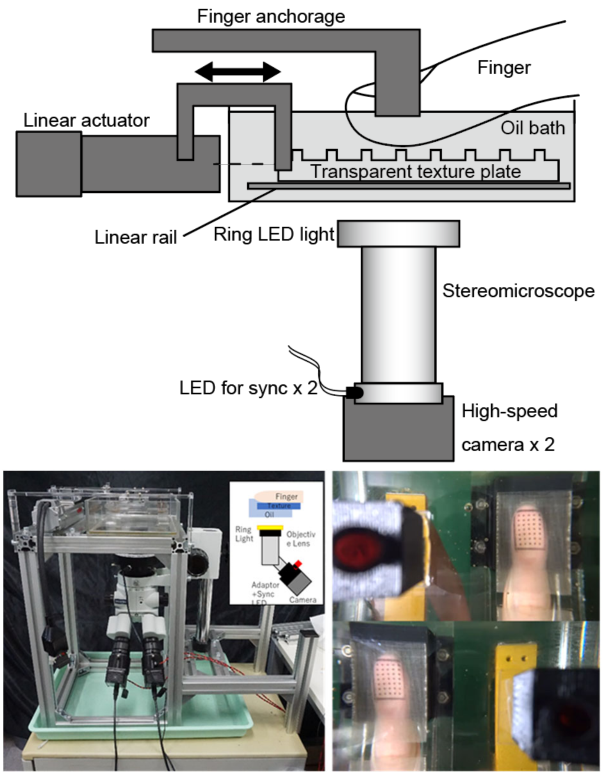

Fig. 2 Measurement of skin deformation.

Fig. 3 shows the measurement results of skin deformation when a sinusoidal texture was traced on the skin [1]. The horizontal axis shows the amount of texture movement, and the vertical axis shows the amount of marker movement in the normal direction of the skin.

This result shows that when tracing a sinusoidal texture, the displacement of the skin in the normal direction is clearly observed to repeat at the same interval, indicating a situation where the shape of the object is copied onto the skin. In other words, it was confirmed that the displacement in the normal direction of the skin was the dominant source of information about the unevenness of the shape.

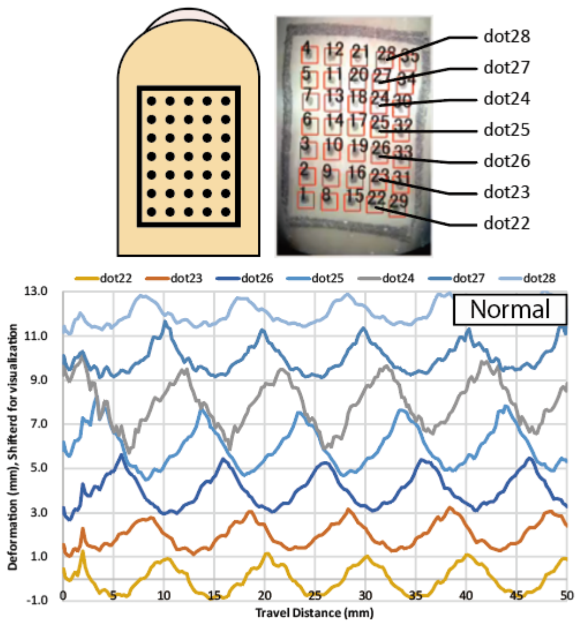

Fig. 3 Measurement of Skin Deformation [1].

Fig. 4 shows the results of skin deformation measurements when tracing 1D gratings (stripe pattern irregularities) of different intervals [2]. The wavelength of the stripes was varied from 0.6 mm to 4.0 mm. When the wavelength is less than or equal to 1.0 mm, the skin deformation is messy and the original stripe shape information disappears. It has been known that human perception of roughness changes at intervals of around 1 mm (macroscopic roughness, or unevenness, is perceived at intervals of 1 mm or more, while microscopic roughness, or friction, is mainly perceived at intervals of 1 mm or less [3][4]).

Using our observation system, we are currently investigating what kind of skin deformation occurs when an illusory phenomenon occurs in the sense of touch. This is expected to clarify the relationship between illusory phenomena and skin deformation, and also to clarify the relationship between tactile feeling and skin deformation.

While the above methods were developed to precisely measure skin deformation, there is also a need to capture the tactile experience of daily life. In such a case, Accelerometer mount on a fingernail is commonly used in such a case, but it can grasp only surface texture information, and cannot grasp how a person is interacting with the object. If the tactile sensations related to such dexterous operations can be recorded and transmitted to a remote location, remote work using tactile sensations will become possible by making the person on the recording side a proxy for the person on the remote side.

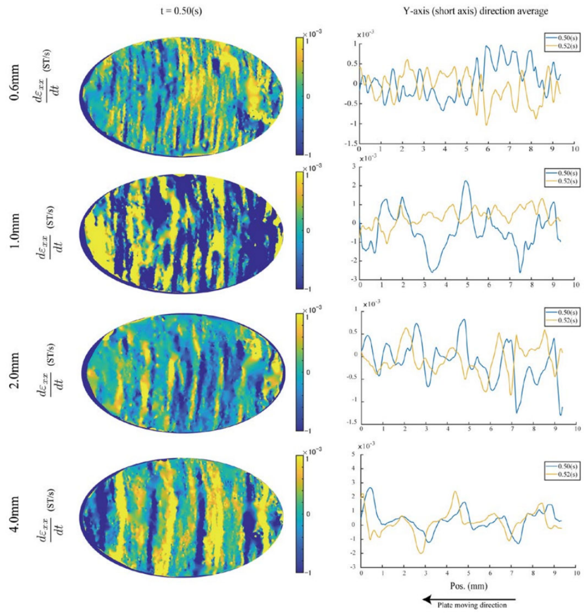

Fig. 4 The frame-to-frame difference of the skin strain change. The results for each texture wavelength are shown from the top to the bottom [2].

In order to record a person's sense of touch in daily life, a wearable type tactile sensor is generally required. Many wearable tactile sensors have been developed so far [5][6], and most of them are in the form of gloves. However, these glove-type tactile sensors have the problem that they themselves interfere with the original sense of touch.

On the other hand, several wearable tactile sensors that do not cover the finger-pad have been proposed. Typical examples are those that measure fingernail color change [7][8], nail deformation [9], and deformation of the side of the finger [10]. However, although these sensors can measure the force applied to the finger, including the direction, they do not provide sufficient information about the contact position and shape of the object.

We have developed a wearable tactile sensing system based on a completely new principle. The proposed method is shown in Fig. 5. An eccentric transducer and a 6-DOF sensor (acceleration and gyro sensor) are mounted on the nail. The finger is vibrated by the transducer and the vibrations are acquired by the 6-DOF sensor. When a finger comes into contact with an object, vibration in a certain axis is disturbed by the contact position and shape, which can be used to estimate the contact position and shape.

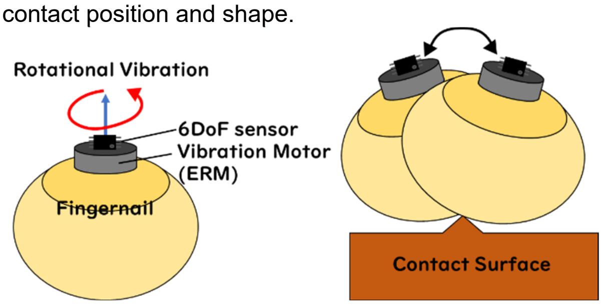

Fig. 5 Fingernail-mounted tactile sensor using excitation by vibration motor.

Fig. 6 shows the actual scene of pattern identification. Here, four contactor patterns have been learned in advance using machine learning (white bars in the figure). We can see that the developed system can indeed recognize the contact target. We are currently at the stage of identifying the pre-learned shapes, but we will tackle the problem of more general shape estimation.

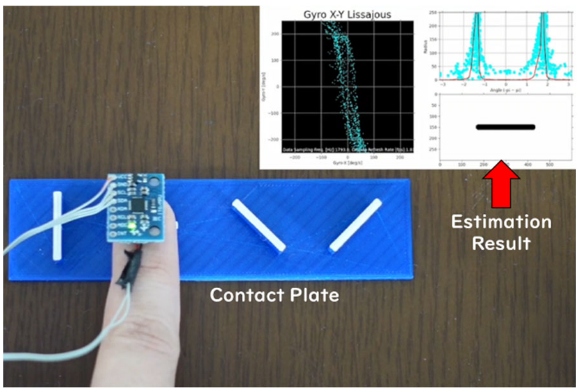

Fig. 6 The shape of the object being touched (horizontal bar in the figure) is identified by the fingernail- mounted tactile sensor.

3 Reproduction of skin deformation

We are developing some tactile sensors to reproduce finger skin deformation and thus to reproduce remote tactile feeling. Important aspects of developing tactile display are that it should be able to present fine spatial information (spatial information), and it should be able to present high-rate temporal information. For example, tactile discrimination threshold of finger-pad is considered to be 2 to 3 mm, and we need dense arrays.

We have developed a new simple principle to realize tactile presentation with high temporal and spatial resolution [11]. The proposed method is based on thermal expansion and contraction of wires. The wire used in this study is not a shape-memory alloy but an electric heating wire, especially Nichrome wire. Since any electrically conductive material that expands and contracts due to heat is a candidate material, the design of the wire is considered to be more flexible than that of the shape-memory alloy-based wire.

Fig. 7 shows the developed tactile display. The vertical black bars are the tactile presentation pins, spaced about 1.2 mm apart. These pins are pulled horizontally from the side by nichrome wires. The Nichrome wire is very thin, with a diameter of 30μm. With such a thin wire, the time required for heating and cooling is short, and it is possible to present tactile sensations perceptible to human up to about 600Hz.

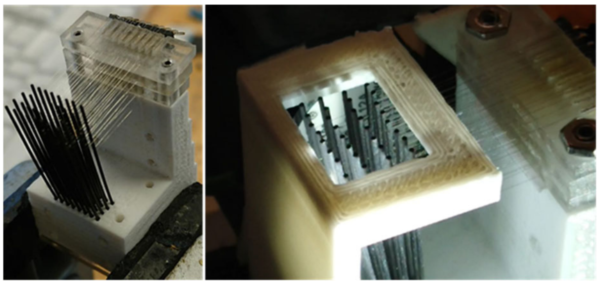

Fig. 7 Dense tactile display using Nichrome wires as actuators [11].

Electrical stimulation is also another candidate to achieve high spatial and temporal resolution relatively easily [12][13]. Since it can be easily configured with electrodes and control circuits, it is small and lightweight. We have achieved to fit 64 stimulation point switching circuits in the size of a fingertip by devising control circuits (Fig. 8)[14].

Our goal is to reproduce the spatial-temporal pattern of tactile sensation on the skin more easily and accurately by using such devices, and thereby to try to reproduce tactile feeling. At present, we have begun to confirm that the illusory phenomenon of tactile sensation is generated by reproducing the skin strain distribution.

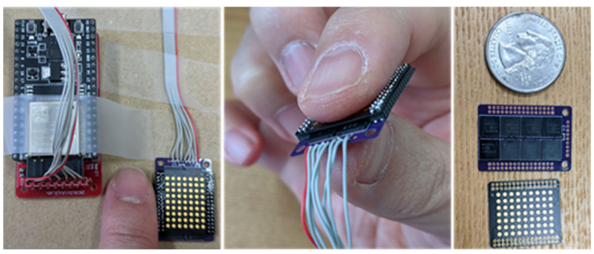

Fig. 8 (Left) Overview of the proposed electro-tactile display kit. (Middle and Right) The fabricated switching board and electrodes [14].

The sense of temperature is also very important in tactile feeling. It is known that people judge the material of an object based on how the temperature drops when they touch it. Many devices have been proposed to reproduce this phenomenon, but they are not suitable for long-term use due to heat buildup when using temperature exchange devices such as Peltier devices.

We considered that electric stimulation can solve this issue to some extent. When we apply electrical stimulation to the forehead, we can feel coldness with a certain probability [15]. We are currently developing a method of cold sensation presentation using electrical stimulation by finding only the points that produce relatively strong cold sensation.

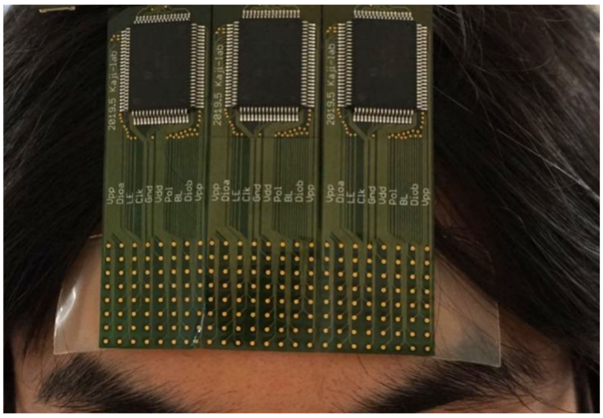

Fig. 9 Presentation of cold sensation by electrical stimulation of the forehead [15].

4 Conclusion

In this paper, we described the development of recording and replaying devices for tactile sensation. For the recording side, we have developed a system that can observe skin deformation when tracing a textured surface. We also introduced a device that combines a transducer and a 6-DOF sensor as a simpler device for recording the sense of touch in daily life.

For tactile reproduction, we introduced two methods that can achieve high spatial and temporal resolution: the first method uses thermal actuation, and the second method uses electrical stimulation. We also showed that the electrical stimulation can also be used for thermal presentation.

As I was writing this article, there was a news about this year's Nobel Prize in Physiology. The award was given for the work on channels involved in tactile and thermosensory receptors. We can say that it foreshadows that future tactile information transmission technology will become a technology to convey tactile feeling beyond mere symbolic tactile information.

Acknowledgment

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