The 18th IEEE International Symposium on
Robot and Human Interactive Communication
Toyama, Japan, Sept. 27-Oct. 2, 2009

Vib-Touch: Virtual Active Touch Interface for Handheld Devices

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***Abstract*— Haptic interaction with handheld devices is limited by space and size constraints that inhibit free hand exploration. We developed a compact haptic interface called Vib-Touch, which is operated by fingertip via a pointing-stick input device containing a tactile feedback. A cursor on the screen could perform virtual exploration as a substitute for the finger movement. We call this technology Virtual Active Touch. We also propose a tactile stimulation method to represent not only tactile sensations, but the whole touch experience, including kinesthetic senses and a sense of shapes perceived by a fingertip. This study reports on the first prototype of the Vib-Touch interface for handheld devices. We confirmed that the prototype could provide friction sensation and geometric shape information using the proposed friction display method.**

I. INTRODUCTION

Haptic interaction in handheld devices will increase their usability and provide impressive new content that visual information alone cannot provide. Several researchers have developed handheld tactile displays [1], [2]. However, their main objective was not to provide rich tactile sensation, but to provide haptic icons as symbolic information only.

Our natural haptic perception requires active hand movement to perceive tactile properties, such as texture, friction, shapes, and softness. One critical problem regarding haptic interaction in handheld devices is that the small size of the hardware limits free-hand exploration. One possible solution is a touch screen with vibratory tactile feedback. Indeed, such a screen has already been installed on several commercial mobile phones. For example, Immersion Corp. has developed tactile feedback technologies for touch screens [3]. However, a vibration-based touch screen is limited in its ability to provide rich tactile sensation because the entire screen vibrates.

We have proposed the concept of 'Virtual Active Touch' to overcome the size and weight limitations of a haptic device [4]. This concept is implemented by applying a tactile feedback function to a pointing-stick-type interface, as illustrated in Fig. 1. The pointing-stick is operated by fingertip and generates tactile feedback. The cursor on the screen can be used to perform virtual exploration as a substitute for the finger without any actual hand movement. In this approach, the tactile stimulator is much smaller than a touch screen and provides richer tactile sensation because a smaller stimulator can more rapidly generate complex waveforms. We have already confirmed the performance of Virtual Active Touch for perceiving roughness [4] and friction [5].

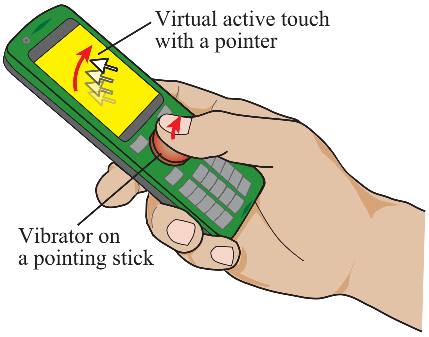

Fig. 1. Concept of virtual active touch [4]

The purpose of this paper is to propose a Virtual Active Touch interface for handheld devices and to develop a prototype. We induce human geometric shape perception using the friction display as an example of its application.

First, we describe the concept of Virtual Active Touch and its applications and explain a friction display. Next, we describe the handheld prototype of the Virtual Active Touch interface. Finally, we examine human geometric shape perception using the friction display.

II. THE CONCEPT OF VIRTUAL ACTIVE TOUCH

A. *Overview*

Virtual Active Touch enables users of mobile interfaces to interact with an object on the screen via a cursor used as a virtual fingertip. This study proposes the addition of a tactile feedback mechanism in a pointing-stick input device to enable virtual active touch. A pointing stick operates by sensing applied force and enables the cursor to be manipulated by the application of a certain amount of force in the desired direction. We call this technology Vib-Touch: 'Vib' is an abbreviation for both 'Virtual active' and 'Vibration'.

Fig. 1 shows an example of a tactile interface to help clarify our concept. The white arrow represents the cursor on the screen. A vibrator is mounted on the pointing-stick input device of the mobile phone and tactile feedback is provided, corresponding to the cursor operation performed using the

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978-1-4244-5081-7/09/$26.00 ©2009 IEEE

fingertip. Using our proposed method, the generation of a vibration in response to virtual active touch can produce various texture sensations [8], [9]. We have already confirmed the performance of Vib-Touch for perceiving roughness [4] and friction [5].

B. Advantages

The advantages of the Vib-Touch interface are summarized as follows.

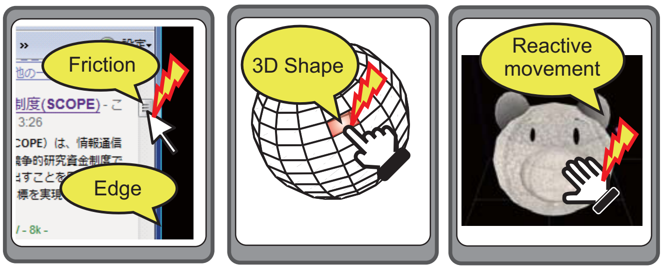
(1) Compact hardware to produce rich tactile sensation: The Vib-Touch interface can be small in size because the size of the tactile display is sufficient enough to cover an area corresponding to one fingertip on the pointing stick. Pointing sticks are compatible with handheld devices and are commonly used.

The Vib-Touch interface has an advantage in that it provides richer tactile sensation compared to that produced by touch screen vibrations. In the case of touch screen interfaces, the entire screen vibrates. It is therefore difficult to convert the vibrations to complex waveforms due to limited actuation responses. However, the Vib-Touch interface can arrange smaller actuators locally. This ability to arrange smaller actuators is advantageous in generating complex waveforms in order to produce rich tactile sensations.

In practice, we need to develop a compact vibrator that is mountable on the pointing stick and that generates vibrations in a wide frequency range with sufficient amplitude. The authors have proposed an ultrasonic vibrator that can be mounted on the joystick of a game controller [10]. This vibrator will hopefully to be used for the Vib-Touch interface, although the generated force is not sufficient enough to produce rich tactile sensations at present.

(2) Adaptability for the screen size: The Vib-Touch interface has few restrictions in terms of the size of the stroking area because cursor movement does not require actual hand movement. For example, if a touch screen tactile display is used for small screens, it is impossible to stroke the object in such a small area. This limited contact results in a lack of immersive sensation in the interface. However, the Vib-Touch interface can adjust the cursor movement according to the screen size. In the case of a small screen, the cursor movement can be restricted by reducing the force scaling factor. With such an adjustment, it is expected that users of mobile interfaces can touch small or large objects on the screen and experience the textures of those scaled objects.

(3) Compatibility with visual effects: The Vib-Touch interface uses the cursor as a virtual finger; operators do not cover the screen with their actual finger. This is compatible with adding visual effects for contact phenomena to the objects on the screen. With touch screens, users cannot avoid obscuring visual cues with their fingers.



(a) Support for GUI (b) 3D contact (c) Haptic interaction

Fig. 2. Applications of Vib-Touch interface

C. Applications

We have confirmed that the Vib-Touch interface enables users to feel texture [4]. The ability to feel more complex textures, such as that of a cloth, is expected to be produced by the tactile synthesis method proposed by the authors [8]. However, we need more useful applications in order to popularize haptic interaction in handheld devices. This study proposes a new approach to induce human kinesthetic sensation using tactile stimulation. Kinesthetic sensation, also known as proprioceptive sensation, is highly related to our motor control and recognition of 3D environments. Conventional haptic interfaces have produced kinesthetic sensation using force feedback devices. However, force feedback devices are too large and too heavy to mount on handheld devices. If kinesthetic sensations can be represented by a small tactile stimulator, we can develop useful applications on handheld devices.

We have proposed a friction display method using vibratory stimulation instead of lateral force [9]. Vibratory stimulation is generated in response to stick-slip transitions between the skin and the contact surface area, depending on hand exploration speed and normal force. We confirmed that friction sensation was represented by tactile stimulation without tangential force.

Fig. 2 shows our targeted applications. As shown in Fig. 2(a), the proposed friction display method can be used to represent friction sensation of sliding objects and sensation of stroking the edge of virtual objects.

In addition, we expect that the cutaneous friction sensation can reproduce a human perception of geometric surface shape, as shown in Fig. 2(b). The perception of geometric shape is regarded as kinesthetic information [6]. Robles-De-La-Torre and Hayward [7] determined that lateral force between the skin and the contact surface area is the main cue in perceiving geometric shape through active touch. If any tactile sensation can substitute for lateral force in shape perception, we can present three-dimensional shapes on a two-dimensional screen without force feedback devices. The shape display can be applied when representing GUI icons such as a button or a slider, 3D-maps, or the movement of shapes.

The last example, as shown in Fig. 2(c), represents the reactive movement of the virtual object. We expect that the Vib-Touch interface can produce the sensation of relative movement between the virtual finger and the virtual object on the screen by connecting with visual cues. This sensation can be used for representing the reactive movement of virtual characters.

In this study, we focus on verifying the 3D shape display induced by the cutaneous friction sensation.

III. FRICTION DISPLAY BY VIBRATORY STIMULI

We use a vibrotactile display method that presents friction sensations to users [9]. The method focuses on the stick-slip contact of finger skin with an object. The method delivers friction sensations by controlling the activity of FA II type tactile receptors at the moment of stick-to-slip transition using high frequency vibrations greater than 200 Hz. These are selected to fit the frequency response characteristics of the FA II type receptor. We used the same stick-slip friction model in a previous paper and improved vibratory stimuli waveforms to produce a more natural friction sensation.

A. Stick-slip Friction Model

The stick-slip phenomena of the contact between finger skin and object surface were simulated using a 1-DOF vibration model with Coulomb friction, shown in Fig. 3. The model approximates the dynamic characteristics of the surface of a finger pad in contact with a flat object in the shear direction. The model involves stiffness k, mass m, and viscosity c. The finger contacts a flat object with normal force N, and lateral friction force F. The velocity of the object is V, and $\dot{x}(t)$ is the relative velocity between the skin and the object. The contact state of the finger (stick or slip) was calculated based on this model. The details of the simulation are described in the literature [9].

Stick-slip phenomena depend on the stiffness and the difference $\Delta\mu$ between the static friction coefficient μ_s and the kinetic friction coefficient μ_k. For example, stick-slip phenomena are less likely to occur with smaller $\Delta\mu$. In order to observe the phenomenon with smaller $\Delta\mu$, the model requires smaller V and higher N.

The parameters (k, m, c) in the friction model affect the frequency of the stick-to-slip transition. We set these parameters so that the frequency of the model was close to that of a real finger pad in contact with a flat acrylic board. This was measured by filming the contact with a high-speed camera. The selected parameter values were as follows: $k = 2.0$ [N/mm], $m = 1.0 \times 10^{-6}$ [kg], and $c = 1.0 \times 10^{-5}$ [Ns/mm].

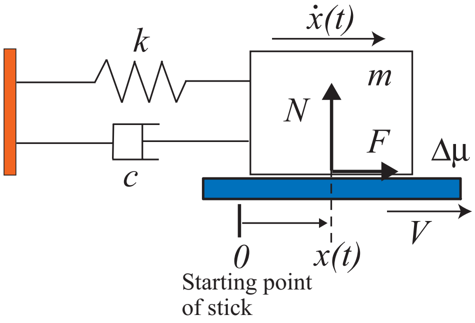


Fig. 3. 1-DOF vibration model of stick-slip motion

B. Control of Vibratory Stimuli

Fig. 4 shows the approach adopted in this report to control vibratory stimuli for simulating friction sensations. The finger pad is given vibratory stimuli according to the timing of the stick-to-slip transitions calculated using the stick-slip friction model. We improved a waveform to have a gradual increase of vibratory amplitude at the moment of stick-to-slip transitions. The previous study used a step increase, which caused a ragged surface sensation.

The intensity of FA II type receptors' activities is controlled by modulating the amplitude of the applied voltage. The maximum amplitude A of the voltage applied to a vibrator is expressed as

$$A = B(\mu_s N - c\dot{x}), \tag{1}$$

where B is constant. The amplitude is proportional to the elastic force at the moment of the stick-to-slip transition, and increases as the static friction coefficient μ_s or the normal force N in the friction model increases. The vibration frequency is constant at 300 Hz. After switching from the stick state to the slip state, the applied amplitude increases linearly for 5 ms and then decreases for 30 ms in a quadratic form.

Fig. 5 shows waves of applied voltage (normal force N = 0.5 or 2.0). Both the amplitude of the applied voltage and the period of the stick-to-slip transition are influenced by N.

IV. EXPERIMENTAL APPARATUS

In order to validate the concept of Virtual Active Touch, a handheld device was developed. The device was named the Vib-Touch interface.

Fig. 6 shows the developed Vib-Touch interface. It is a box, the dimensions and weight of which are $185.5 \times 81 \times 39$ mm and 268.1 g. A liquid crystal display (CENTURYCplus one LCD-4300J) with 800×480 pixels was installed in the center of the device. A pointing stick with a tactile stimulator was located in the right portion of the device, assuming users would operate it with their right thumb.

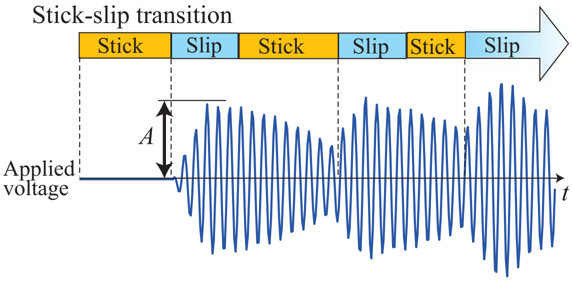
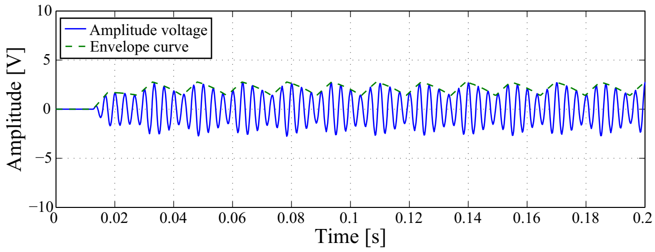
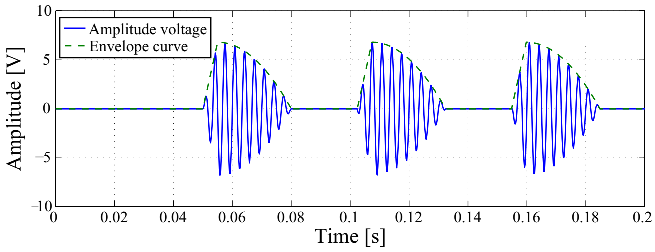


Fig. 4. Control of vibratory stimuli



a) Normal force = 0.5 N



b) Normal force = 2.0 N

Fig. 5. Waveforms of the vibratory stimulation corresponding to changes in normal force

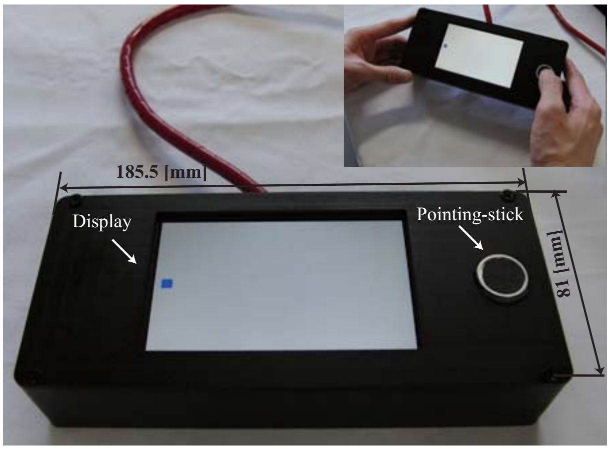


Fig. 6. Vib-Touch interface design

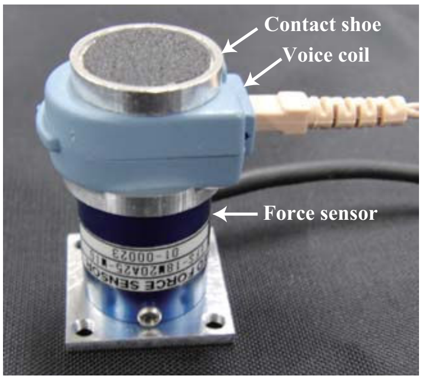


Fig. 7. Pointigng-stick interface with a tactile stimulator

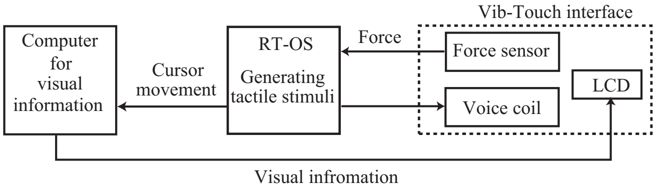


Fig. 8. System diagram

The pointing stick is shown in Fig. 7. It consists of a voice coil (AEC, TACTAID VBW32) as a tactile stimulator and a six-axial force sensor (NITTA, EFS-18M20A25-M10). A contact shoe was attached on top of the voice coil to provide an adequate area between the fingertip and the voice coil. The shoe is circular, with a diameter of 18 mm.

As shown in Fig. 6, the user of the device holds it with both hands and manipulates a cursor on the computer screen with his right thumb. When the user applies tangential force with his fingertip to the pointing device, the cursor moves according to the applied force. Depending on the cursor velocity and the applied force in the normal direction of the pointing stick, vibrotactile stimuli are presented to the user on the basis of the algorithm described in Section III.

Fig. 8 shows the signal flow of the entire system. The force exerted by the user was sensed by the force sensor and transferred to the computer with a real-time operating system (OS). The sampling frequency of the force data was 5 kHz. The real-time OS computed the tactile stimuli delivered to the user. Also, the cursor movement was computed by the real-time OS and sent to another computer to produce visual information.

We employed a linear transformation between the applied force $f(t)$ and the cursor velocity $v(t)$. The transformation equation is expressed as

$$v(t) = \alpha f(t), \tag{2}$$

where α works as a gain. Taking account of the size of the screen, this value was set to 80 [mm/Ns] so that users can

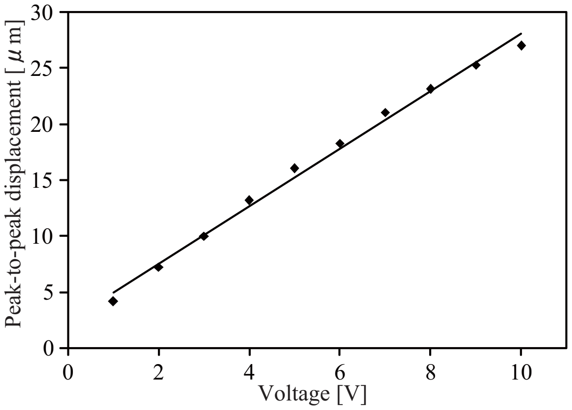


Fig. 9. Relationships between applied voltages and generated displacements on the driven frequency of 300 [Hz]

easily manipulate the cursor. The velocity $v(t)$ corresponds to V in the friction model in Fig. 3.

Fig. 9 shows peak-to-peak displacements generated by the voice coil when sinusoidal voltages of 300 Hz, used for the experiment in this study, were applied. It showed a linear relationship between the applied peak-to-peak voltages and generated displacements.

V. EVALUATION OF THE PERCEPTION OF SURFACE SHAPES BY FRICTION SENSATION

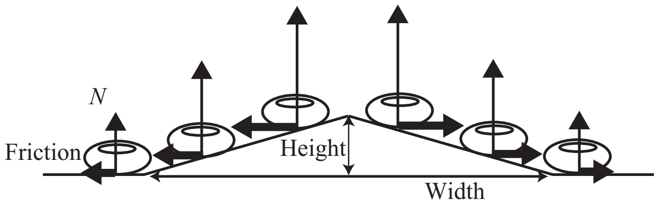
A. Purpose

We examined the possibility of representing geometric shapes by changing the friction sensation as an example of kinesthesia induction by tactile perception, as described in Section II. We confirmed whether geometric shapes could be perceived by changing the friction during touch movement. In this study, we aimed to represent the shapes of bumps.

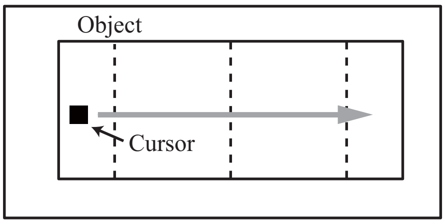
To control the friction sensation, normal force was increased artificially. The method we suggested for synthesizing a friction sensation is based on the Coulomb friction model. Therefore, as normal force increases, lateral force (fixing strength) increases and as normal force decreases, lateral force (fixing strength) decreases. Moreover, the period of the stick-slip transition is influenced.

It appears that a higher bump is perceived as the amount of normal force change, that is, ΔN is larger. A wider bump is perceived as the span L of the change of normal force, as shown in Fig. 10.

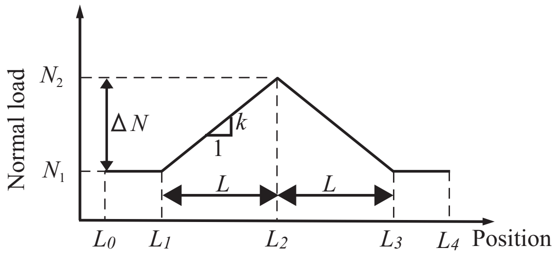
We confirmed whether the height and width of a bump could be represented by changing the friction sensation and we examined the effects of ΔN and L.



(a) Perceived bump



(b) Visual information on the screen



(c) Normal load function

Fig. 10. Tactile height illusion via virtually controlling normal finger-force

B. Task and Procedure

The virtual normal force was increased from N_1 to N_2 over a span L when a user stroked a virtual object on a computer screen, as shown in Fig. 10. After the virtual normal force was increased to N_2, it was decreased from N_2 to N_1 over a span L. The normal force was $N_1 = 0.5$ and N_2 was on the middle of the screen. The normal force $N(x)$ at position x was expressed as

$$N(x) = \begin{cases} N_1 & (L_0 \le x < L_1) \\ k(x - L_1) + N_1 & (L_1 \le x < L_2) \\ -k(x - L_2) + N_2 & (L_2 \le x < L_3) \\ N_1 & (L_3 \le x < L_4), \end{cases} \tag{3}$$

where

$$k = (N_2 - N_1)/(L_2 - L_1). \tag{4}$$

Five values of ΔN= 2.0, 3.0, 4.0, 5.0, 6.0 [N] and a value of $L = 20$ were used to evaluate the effect of ΔN on the perceived height of the bump. Five values of L= 10, 15, 20, 25, 30 [mm] and a value of $\Delta N = 4.0$ were used to evaluate the effect of L on the perceived width of the bump.

Since the aim of this study was to confirm that participants could perceive 3D shapes only with tactile stimuli, visual information relating to the 3D shapes was not presented to them. The visual information given to the participants was a blue square representing the cursor, which was approximately 3 × 3 mm, as shown in Fig. 6.

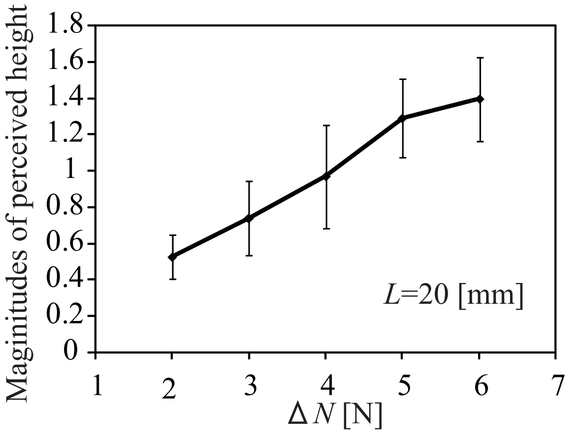


Fig. 11. Magnitude of perceived height

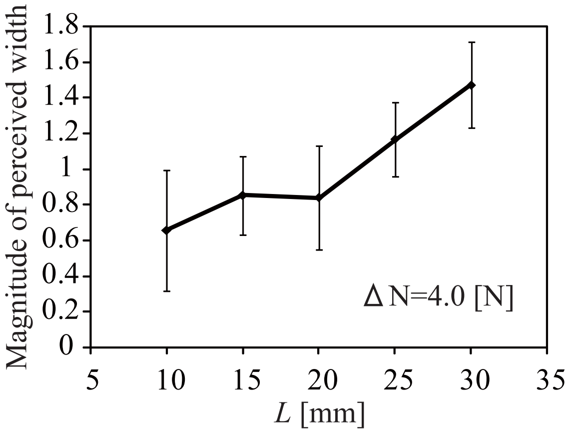


Fig. 12. Magnitude of perceived width

A magnitude estimation method was used to evaluate the perceived height and width of the bump. Participants were asked to subjectively assign an arbitrary number to quantify the perceived height and width within 30 seconds. Each stimulation combination was presented twice. Each participant evaluated one set (20 trials) of experiments about perceived height and width. The order of the stimulation combinations was random and the order of the experiments was changed. Participants practiced before the experiments. They wore headphones through which pink noise was played to cover the sounds generated by the vibrator. Five men and one woman aged from 20s to 30s performed the tasks.

C. Experimental Result

The magnitudes of perceived height and width were calculated as the geometric average of the normalized results from all participants. Fig. 11 shows that the perceived height increased as ΔN increased. Fig. 12 shows that the perceived width increased as L increased. These results corresponded to our expectations.

The proposed method was used to represent the height and width of the bump. We confirmed that the height was controlled by ΔN and the width was controlled by L.

VI. CONCLUSIONS

This study proposed the concept of Virtual Active Touch and developed a prototype for the Vib-Touch interface. We reported a new approach to induce human geometric shape perception using the proposed friction display method. We implemented the friction display method for the prototype and confirmed that the proposed method could control the height and width of bumps. Representing shapes using the proposed method is expected to be applied when representing things such as GUI icons such as a button or a slider, 3D-maps, and the movement of shapes, etc.

VII. ACKNOWLEDGMENTS

This research was supported by the Ministry of Internal Affairs and Communications, Grant for the Strategic Information and Communications R&D Promotion Programme (SCOPE) #082102006.

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