Surface Haptics Using Ultrasonic Vibrations

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Abstract

This paper deals with "Surface Haptics," especially for control of tactile sensation. Diminished and created tactile sensations are described. Tactile sensation during rubbing motion on an object can be diminished by squeeze film effect induced by vertical ultrasonic vibration. The experimental setup to demonstration "Diminished Haptics" is presented. Alternatively, tactile sensation, especially for roughness sensation, can be created by friction control managed by surface acoustic wave (SAW). The first prototype of the display and a controller are reported. Additionally, the principle has been expanded to realize pen-tablet type tactile display to indicate drawing sensation during drawing lines on paper by charcoal.

Keywords: Haptics, Tactile sensation, Ultrasonics, Surface acoustic wave

1. Introduction

These days, indication of human tactile sensation has attracted many attentions. The indication can be applied in many fields such as virtual reality, computer interface and so on. To indicate the sensation, proposed devices have employed actuators to deform our finger skins (for example, [1]-[4]). Recently, "Surface Haptics" has drawn interests as many types of touch screen become widely used. For the purpose of controlling tactile sensation on a flat surface, reduction or creation of tactile sensation are effective.

To diminish tactile sensation of the solid surface, squeeze film effect can be applied [5][6]. When the surface on which texture can be perceived by operators is ultrasonically vibrated, perceived tactile sensation can be reduced or diminished. To excite the strong intensity ultrasonic vibration, a Langevin type transducer is used.

To create tactile sensation on the surface, friction control with ultrasonic vibration has been focused by some researchers [7]-[11]. In Saitama University, we focused friction control using surface acoustic wave (SAW) and applied it to the actuation in tactile display. Properties of SAW are high operating frequency of more than a few MHz, thin structure, simple fabrication, easy installation of a transducer, high energy density and so on. A thin tactile display with high performance can be developed using SAW properties. In the case of application of the friction control with SAW, fast response can be expected. Therefore, indication of roughness and its difference can be expected. To expand application, SAW tactile display principle was applied to realize a pen-tablet type tactile display.

2. Diminishing tactile sensation

Principle

Figure 1 shows principle of diminishing tactile sensation of solid surface. If we rub a solid surface with texture by our finger, tactile sensation according to the texture can be perceived as shown in left side of the figure. Vibrating the surface in the vertical direction at ultrasonic frequency, squeeze film is induced between the finger and the surface. Surface of the finger cannot touch according to the pressurized air film. As a result, the finger cannot experience the texture on the solid surface. For us, the tactile sensation of the surface texture is diminished.

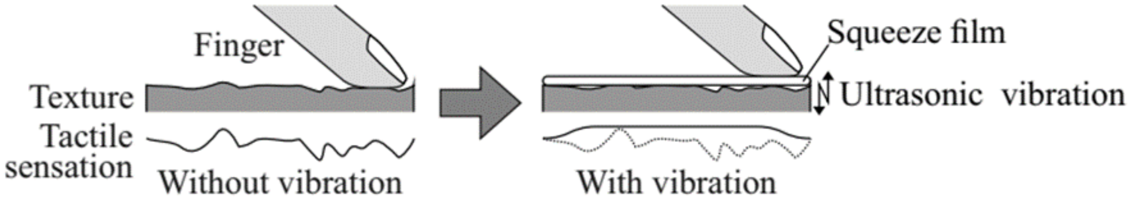


Fig. 1 Diminishing tactile sensation of solid surface

System development

To realize diminution of the tactile sensation of solid surface, diminishing tactile sensation system was developed. The system is shown in Fig. 2 and consisted of an ultrasonic transducer unit and a driver unit. The transducer unit contained a Langevin type ultrasonic transducer as shown in Fig. 3. A horn was shaped into cylinder and coupled to the transducer. Top surface of the horn was machined into square as shown in the figure. The square surface played a role of real object to be rubbed. To change the texture of the object, sheet-like material, such as sandpaper, cloth and so on, can be attached by double-sided tape. If an operator touches the material surface, he/she can perceive the material texture as natural experience. Once ultrasonic vibration is excited, the tactile sensation can be diminished by the squeeze film induced between his/her finger and the material surface.

Fig. 2 View of diminishing tactile sensation system

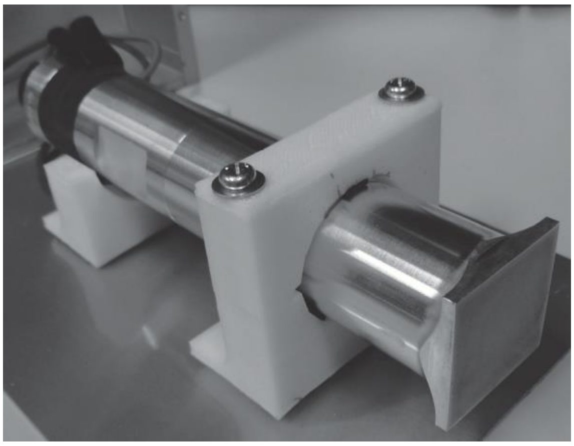


Fig. 3 Langevin type ultrasonic transducer with horn

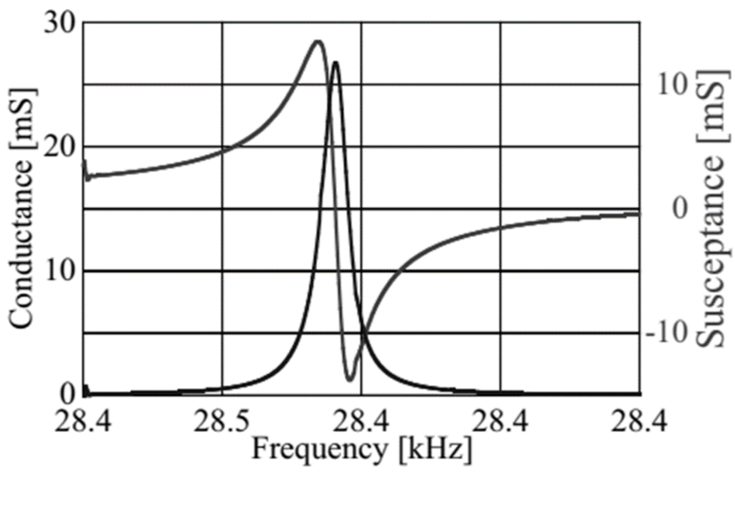


Fig. 4 Electrical characteristics of ultrasonic transducer

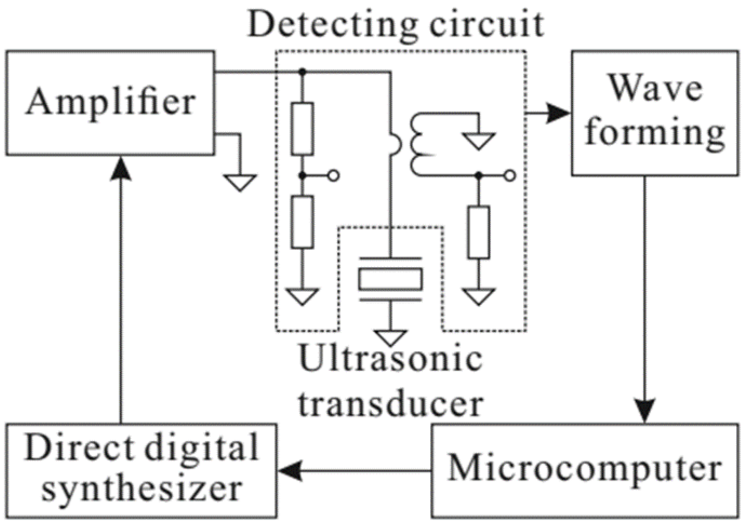


Fig. 5 Driver with resonance frequency tracking system

Resonance frequency of the Langevin type ultrasonic transducer was 28.4 kHz approximately. The coupled horn was designed with a help of FEM analysis so that its 1st order longitudinal vibration mode resonance frequency could be tuned to 28.4 kHz. The horn was machined and coupled to the Langevin transducer by a bolt. Measured electrical characteristics of the assembled transducer are plotted on Fig. 4. Resonance frequency of the transducer was 28.58 kHz. Q factor was 1240. Due to the high Q factor, the resonance frequency of the transducer might be shifted easily due to touch of the finger. The driver contained the function to track the resonance frequency shift[12]. To track the shift, the driver illustrated in Fig. 5 was used. Commonly, phase difference between the alternative voltage applied to the ultrasonic transducer and the current flowing into it becomes constant value. In the driver, phases of them were detected by the circuit drawn in the figure. Then, their difference was measured by microcomputer RX-621. Updated operating frequency was calculated also by the microcomputer. A direct digital synthesizer communicating with the microcomputer was used to generate operating alternative voltage to be applied to the transducer. The voltage was amplified by a power amplifier. During experience of diminishing tactile sensation, participants could enjoy the tactile sensation diminished by the squeeze film caused by stable ultrasonic vibration.

Demonstration

To demonstrate the tactile sensation diminished by the squeeze film, a sand paper was attached on the top of the ultrasonic transducer by double-sided tape. When we touch its surface, we feel roughness of the paper. Once ultrasonic vibration was on, the roughness sensation was diminished, then we felt as we were touching very smooth surface. This type of demonstration was performed during Asia Haptics 2014 held in Tsukuba, Japan.

Then, only the double-sided tape was attached on the top. If we touch the surface, we feel stickiness. Once the vibration was on, we could feel smoothness. The demonstration with the double-sided tape was performed in demo session of World Haptics Conference 2015 held in Chicago, USA. To surprise participants, the ultrasonic vibration was excited in advance. They were asked to touch the top surface gently and felt smoothness of the squeeze film. Suddenly, the vibration was stopped and their fingers were stuck on the tape. All participants were surprised at this moment.

3. Creating tactile sensation

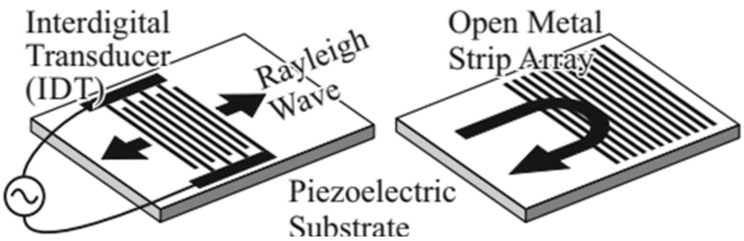
Surface acoustic wave

Figure 6 (a) indicates the excitation of Rayleigh wave, a kind of SAW. An interdigital transducer (IDT) is arranged on a piezoelectric substrate (Single crystals are usually used for SAW devices). The IDT consists of a metal strip array. When AC driving voltage is applied to the IDT, Rayleigh wave is

excited and propagates on the substrate surface in the direction indicated by the arrows in the figure. The frequency of the driving voltage is decided according to the size of the IDT, particularly pitch of the IDT electrodes. The substrate is also used as a medium on which Rayleigh wave propagates. In the case of Rayleigh wave, the vibration propagates with gathering its vibration energy of more than 90 % in the medium surface of 1 wavelength depth. Therefore, the substrate can be fixed easily, for instance, by applying cement on backside of the transducer.
Standing wave of the Rayleigh wave can be generated easily by combination of two opposed progressive waves. To excite the standing wave, two opposed IDTs or two reflectors with IDTs are required on the piezoelectric substrate surface. The reflector is configured by an open metal strip array (OMSA), as shown in Fig. 6 (b). The IDTs and the reflectors can be formed simultaneously by using a photolithography process.

SAW tactile display

The schematic diagram of basic structure of the SAW tactile display is shown in Fig. 7. A display operator rubs a stator transducer through a slider, which is consisted by an aluminum film. The film enhances the friction reduction effect mentioned bellow and also protects operators' fingers from high power/frequency ultrasonic vibration. He/she can rub the area between the IDTs. Tactile indication principle in our research can be applied to pen-tablet type interface as shown in Fig. 8. In this set up, operators can enjoy the sensation while they draw a line with charcoal on craft paper. On the top of the pen, rubber film and the aluminum film were attached. The rubber film plays a role of finger skin in the basic configuration.



(a) Excitation (b) Reflection

Fig. 6 Excitation and reflection of SAW

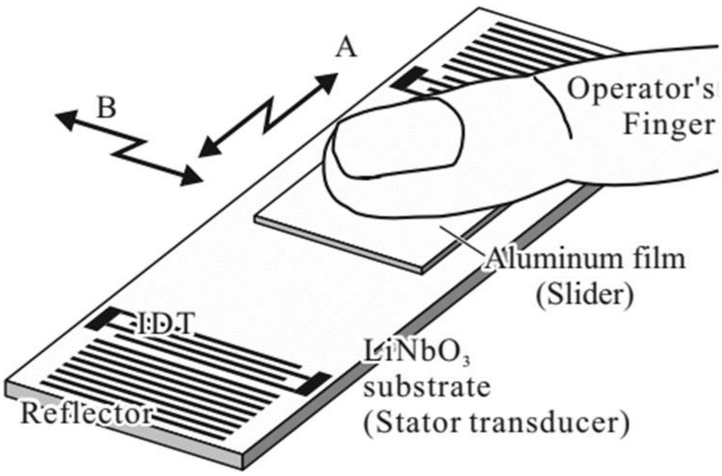


Fig. 7 Basic structure of SAW tactile display

While the finger travels on the SAW transducer, it experiences kinetic friction between the slider and the transducer, as indicated by Fig. 9 (a). When an AC driving voltage is applied to the IDTs, the SAW is excited and propagates on the substrate surface then forms the standing wave. Under the rubbing motion, the friction is reduced by mechanical vibration of the SAW, as illustrated in Fig. 9 (b). With repeat of switching the SAW on and off by pulse modulated driving voltages, the friction

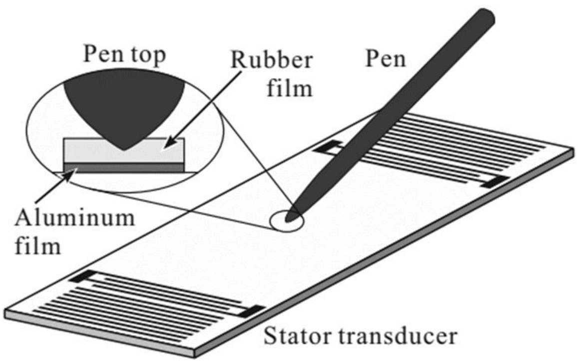
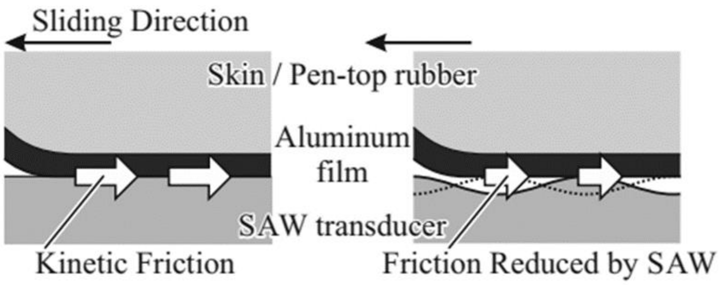


Fig. 8 Pen-tablet type SAW tactile display



(a) Without SAW (b) With SAW

Fig. 9 Friction shift by switching SAW

can be switched discretely. The slider experiences the repeat of the normal friction and the reduced friction. The repeat results in the vibration under the rubbing motion. Therefore, the vibration can be produced according to the switching. To recognize the controlled friction, the operator must rub the substrate surface with his/her finger through the slider. If the amplitude of the driving voltage is modulated by analog signal, the friction can be arranged continuously. This means that amplitude modulation as well as the switching can be applied to control the vibration on the finger and the pen top.

Control

Figure 10 indicates an example of control system for the SAW tactile display. A motion detector such as an encoder or a camera is attached to the display to detect the position of the finger/pen. Rubbing/drawing speed v_m [m/s] can be calculated from derivative of the position. Frequency and duty ratio of the control pulses to switch the SAW is decided according to parameters stored in the system. In our equipment, the parameters can be modified by a host computer. Typically, the frequency f is decided by the following equation

$$f = \frac{v_m}{k_r} \tag{1}$$

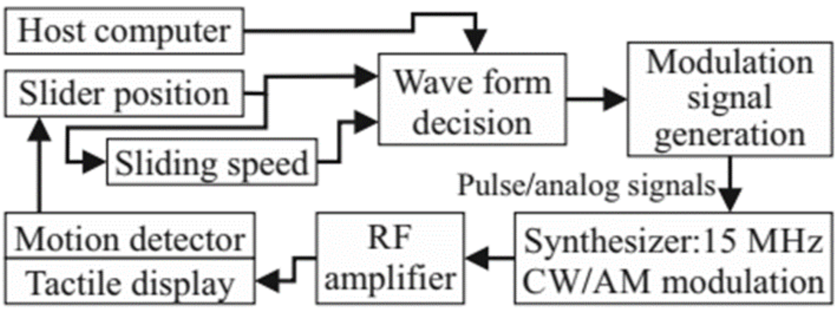


Fig. 10 SAW tactile display control system

where, k_r [m] was a stored parameter. Normally, the frequency is DC-1 kHz variable. Generated pulse waves are transmitted to a synthesizer and switch the driving signal of SAW. The driving signal is amplified by a RF amplifier and provided to IDTs on the SAW transducer in the tactile display. Basically, analogue signals can be applied instead of the pulse waves. In this case, the friction can be arranged precisely. Therefore, various and realistic tactile sensation can be expected. Amplitude modulation is applied instead of switching in the synthesizer.

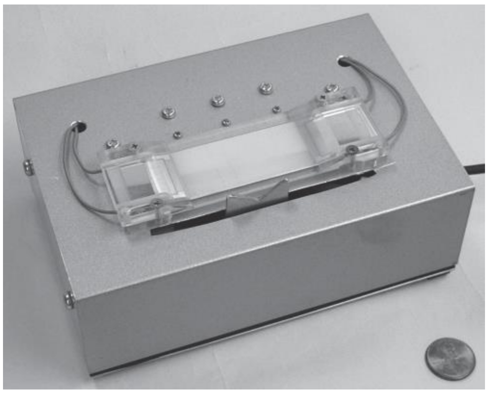


Fig. 11 Prototype of SAW tactile display

Demonstration

A prototype of the SAW tactile display was fabricated according to the principle. Figure 11 is a photograph of the display. A $LiNbO_3$ wafer was applied as the piezoelectric substrate. Two IDTs were arranged on the surface and two reflectors were formed behind each IDT. The electrodes were covered by acrylic resin shells. In this prototype, rubbing motion was limited in one dimension with available rubbing stroke of 50 mm. Operator's finger was guided by a linear guide with an encoder to detect the slider position. For this prototype, controlling system was embedded in a microcomputer (SH2/4075F) so that it could work at standalone situation. Under the control described above, slider speed was measured. The result of the measurement is plotted on Fig. 12. It was observed that the slider vibration frequency could be controlled according to the control pulse signal. Roughness sensation was successfully indicated. Slider velocity was measured by a laser Doppler velocity meter under the control situation. The measured velocity is plotted on Fig. 12 with the control pulse. It can be seen that the velocity was accelerated and deaccelerated according to the control signal. Additionally, M sequence random number was referenced to generate control signal for control of the pen-tablet type tactile display[13]. Frequency of pen vibration as a result of tactile display control had fluctuation. With this control, we could feel more natural drawing sensation.

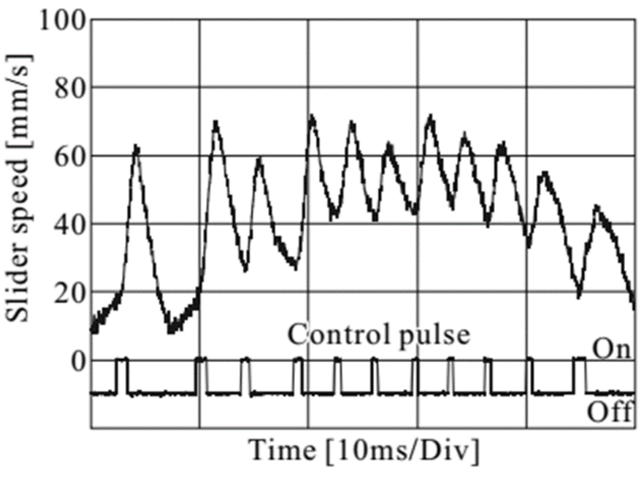


Fig. 12 Measurement result of slider speed

4. Summary

As a part of surface haptics, control of human tactile sensation was introduced. By using ultrasonic vibration, the sensation could be diminished or created. To realize such control, ultrasonic transducers and controllers were designed and fabricated.

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