Tactile Display of Surface Texture by use of Amplitude Modulation of Ultrasonic Vibration

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Abstract—**In the present study, tactile display of surface texture by use of amplitude modulation of ultrasonic vibration is developed. First, systems are constructed to display artificial tactile sensation using ultrasonic vibrator. Then, sensory evaluation experiments are conducted to confirm that output stimulations in response to hand velocity is effective to realize an artificial tactile sensation. Next, it is confirmed that the proposed method to display roughness of a real cloth was more effective than existing method. Then, we evaluated the tactile sensation of a real cloth and a tactile display quantitatively using SD (semantic differential) method. As a result, at the evaluation item on roughness, the correlation coefficients between a real cloth and an artificial tactile sensation using proposed method was quite high. In conclusion, it is confirmed that realistic surface texture can be displayed by use of amplitude modulation of ultrasonic vibration.**

Keywords- tactile display; texture; ultrasonic vibration; amplitude modulation

I. INTRODUCTION

Tactile displays are expected as a new device for virtual reality and tele-robotics because they can display texture, softness and geometry of virtual or remote objects. They are expected to be used at home and medical environment. Hence, numbers of tactile displays for human finger pads utilizing different principles have been introduced. Ikei [1] utilized vibrating pin array for tactile stimuli. Yamamoto [2] utilized electrostatic actuator for displaying surface roughness. Asanuma [3] utilized air force for selectively stimulating finger pad. Kajimoto [4] stimulated tactile receptors directly by using electric signal. Authors [5] developed a tactile display by use of ICPF (Ionic Conducting Polymer gel Film) actuator array. It is shown that texture of various surfaces can be displayed by stimulating tactile receptors using the most sensitive frequency of each tactile receptor. However, those tactile displays are not small and reliable enough. So, small and reliable devices are expected to be realized. Ultrasonic vibration is one of the candidates of tactile displays because mechanical vibration have following characteristics; larger the frequency is, smaller the amplitude is for producing certain output power. Small-sized ultrasonic vibrator can not only used for moving the rotor/slider but also for stimulating mechanoreceptors of humans. Hence, several tactile displays by use of ultrasonic vibration have been proposed [6][7][8]. Takasaki [6] utilized SAW device for the vibrator. It is shown that human can feel the tactile sense when the burst-wave-form input is applied. Biet [7] showed that vibrator for ultrasonic motor can be used for displaying periodic signal over traveling wave similar to the Takasaki's idea. However, those ultrasonic devises have limitations as follows: (1) They have been used to display information including only a certain frequency. (2) Moving range has been limited because the subject finger slides over the ultrasonic tactile display. Hence, in the present study, we test if the ultrasonic vibrator can be used to display precise surface geometry of various objects by use of amplitude modulation of ultrasonic wave using the waveform representing the realistic surface geometry. We also test if subjects can feel the tactile stimuli to be similar to the realistic touch on various surfaces when vibrator moves with the finger movement. Finally, it is concluded that the proposed method, amplitude modulation by use of the realistic wave form is useful to display the texture of surface geometry.

II. PROPOSED METHOD AND EQUIPMENT

There are about four types of tactile receptors in the skin of humans. Each tactile receptor has its own receptive field and frequency. Figure 1 shows the amplitude threshold of three types of tactile receptors named SA I, FA I and FA II. SA represents for slowly adaptive tactile receptors, whereas FA represents for fast adaptive tactile receptors. Type I and II represents for tactile receptors having narrow and wide

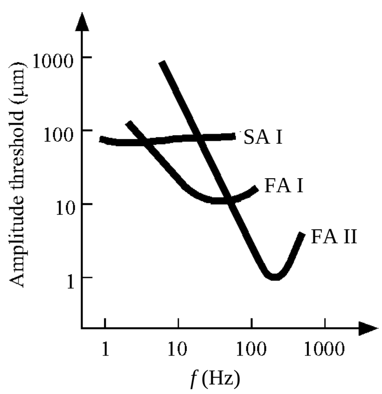


Fig. 1 Thresholds of tactile receptors for vibratory stimulus

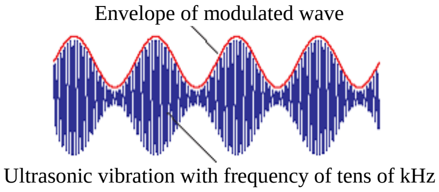


Fig. 2 Schematic view of amplitude modulation of ultrasonic vibration

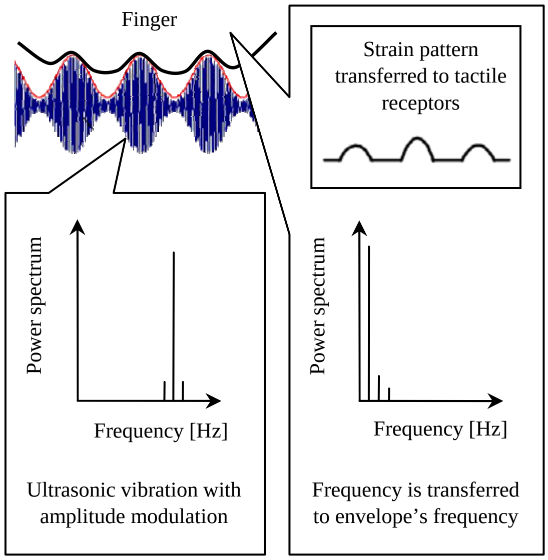


Fig. 3 Nonlinear transformation of time-space frequencies due to contact between finger and vibrator

receptive field, respectively. (SA II is not shown.) As shown in Fig. 1, each tactile receptors share the frequency information. In other words, they have their own frequency range, i,e, SA I is for static and low frequency stimuli. FA I is for stimuli around several tens of Hz. FA II is for stimuli for around several hundred Hz. Several previous tactile displays [5][6][7] have stimulated a certain type of tactile receptor by a single frequency stimuli. For example, 20 Hz and 200 Hz stimuli are used simultaneously to stimulate FA I and FA II tactile receptors, respectively.

Principle of When the amplitude modulation (AM) of ultrasonic vibration is as follows: As shown in Fig. 2, ultrasonic vibration having frequency of tens of kHz is modulated by a wave having smaller frequency within a detective range of tactile receptors. An envelope of the AM wave is as shown in the Fig. 2. Then, as shown in Fig. 3, human finger pad can response to the envelope of the AM wave, because the range of response frequency of human finger is smaller than the ultrasonic range. Hence, strain pattern detected by tactile receptors are similar to the deformation pattern of the finger as shown in Fig. 3. As a result, Frequency is converted from ultrasonic range to

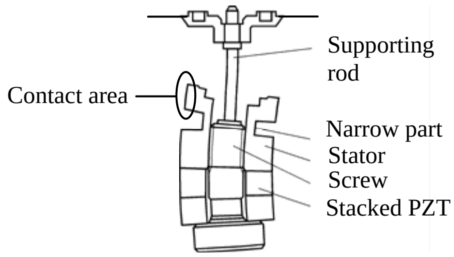


Fig. 4 Cross- section diagram of a bar-type ultrasonic motor by use of first bending modes

receptive range of humans. In other words, human can detect only the pattern of envelope of the AM ultrasonic wave.

In the Fig. 2 and Fig. 3, envelop of the AM wave represents only one frequency. What if the envelope of AM wave represents various frequencies similar to real object surface? This is the first question answered in this paper. Hence, the real waveform is used for the AM wave form.

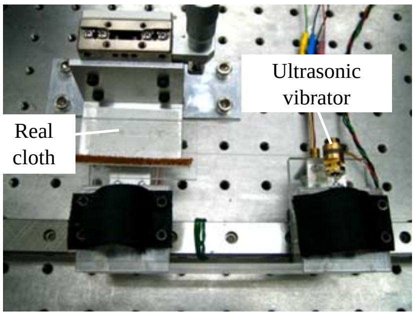
The other question is as follows; What if the ultrasonic vibrator is moved with the finger pad and frequency of AM wave is changed in accordance with the velocity of finger movement? If it is possible, ultrasonic vibrator can be small enough to be attached underneath the finger. The ultrasonic vibrator doesn't have to have large surface like ones in previous studies [6][7]. The method is simple. Assume that the wavelength of the real surface is $\lambda(x)$, where x is a location on the surface. Then the frequency of AM wave, $f(t)$, can be calculated by,

$$f(t) = v(t)/\lambda(x) \tag{1}$$

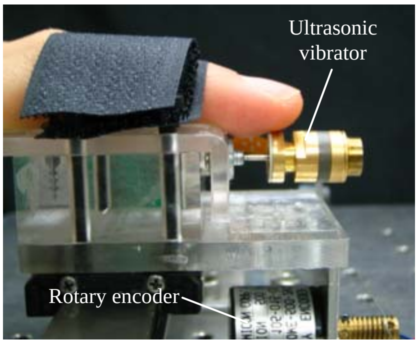
where, $v(t)$ is a velocity of a finger movement as a function of time t. It means that if the $\lambda(x)$ is measured in advance and $v(t)$ is measured in real time, then $f(t)$ can be obtained.

Figure 4, 5 and 6 show ultrasonic vibrator, entire equipment and AM wave control system, respectively. As shown in Fig. 4, a vibrator of a bar-type ultrasonic motor used for auto focus lenses produced by Canon [9][10] is used for the ultrasonic tactile display. Rotor is removed and the plane side portion of the vibrator is used as a contact area (see Fig. 4 and Fig. 5 (b)). Elliptic motion at the surface of the vibrator is excited using two perpendicular first bending modes of the vibrator. As shown in Fig. 5 the ultrasonic vibrator and finger are fixed on a slider that can be moved only in lateral direction, i.e. ultrasonic vibrator moves along with the finger. Movement of the slider in lateral direction is measured by rotary encoder attached to the slider. In Fig. 5 (a) it is shown that the texture of real cloth is compared with the one by stimuli using ultrasonic vibrator.

Figure 7 shows the tactile displaying system in response to the velocity of human hand. FPGA is used for producing the AM waveform applied to the ultrasonic vibrator.



(a) Experimental setup to compare texture of real cloth and ultrasonic tactile display



(b) Close-up view of vibrator and finger

Fig. 5 Equipment of tactile displaying experiment

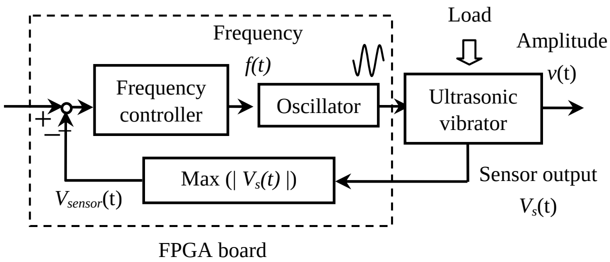


Fig. 6 Amplitude control system

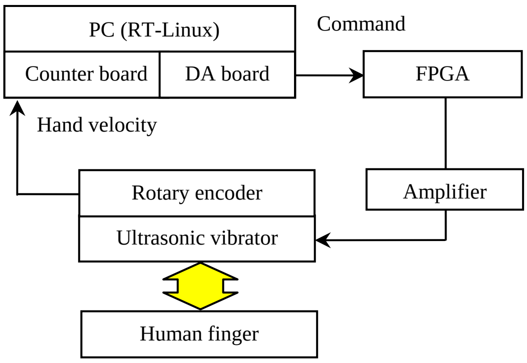
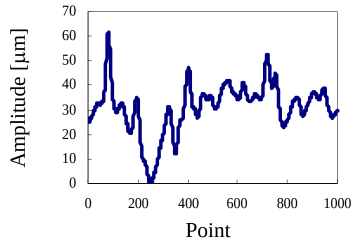
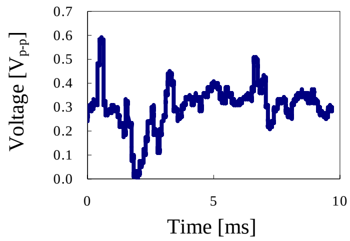


Fig. 7 Display system in response to the velocity of human hand



(a) Surface geometry of real cloth (denim)



(b) Generated waveform representing real cloth

Fig. 8 Geometry of real cloth (Denim) and regenerated wave form

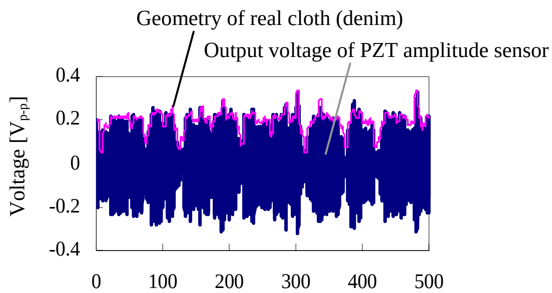


Fig. 9 Command input of real cloth and sensor output

III. EXPERIMENTAL RESULTS

First, it is confirmed that the above mentioned equipment can generate the required AM waveform.

Figure 8 shows the geometry of real cloth (Denim) and regenerated wave form. Fig. 8 (a) shows the displacement of real denim. Fig. 8 (b) shows the generated waveform representing the denim when the finger velocity is constant. We can conclude that both waveforms are close enough.

Figure 9 shows a comparison between the geometry of real cloth (denim) and generated AM waveform of ultrasonic vibrator measured by PZT amplitude sensor as a voltage output when the velocity of finger movement is constant. The amplitude sensor is made of PZT placed in the stacked PZT shown in Fig. 4. It is shown that the envelope of the generated AM waveform is similar to the real geometry.

It is also confirmed that the AM waveform follows the real geometry in accordance with equation (1) even when the velocity of finger is changed.

Six objects are used. They are paper, sheepskin, silk, velour, nubuck and denim.

Now, the following four experiments, (a) to (d), have been conducted to confirm the proposed method.

(a) Should the waveform be changed in accordance with the velocity of finger?

(b) Can the difference of clothes be displayed?

(c) Is the AM waveform of realistic geometry effective?

(d) Is fusion between realistic waveform and selected frequency effective?

Results of those four experiments are described below.

A. Should the waveform be changed in accordance with the velocity of finger?

We compared the following two situations. First one is to change the waveform when the velocity of the finger is changed. The other is the case when the waveform is not changed even when the velocity is changed. Fifteen subjects are asked to compare which case is much closer to the real texture. Objects are waveform of paper, sheepskin, silk, velour, nubuck and denim. As a result, all the subjects say that the texture is closer when the waveform is changed with finger velocity change.

B. Can the difference of clothes be displayed?

Twenty subjects are asked to compare seven vibratory stimuli and answer which one correspond to seven original texture, respectively. As a result, correct ratio is larger than 50 percent in all the cases. Especially, correct ratio is larger than 80 percent in case of sheepskin and silk. We can conclude that it is easy to display texture of sheepskin and silk. On the other hand, paper was often misunderstood as sheepskin or silk. Softness of paper should somehow be represented.

C. Is the AM waveform of realistic geometry effective?

In our previous study, it is shown that stimulation for FA I and FA II receptors by using the selected unique frequencies are effective [5]. Hence, we compare the AM stimuli including only 5Hz and 200Hz component with the AM wave including all the frequency of real clothes. As a result, in most of the case, AM wave including all the frequency is better displaying realistic texture. However, softness and wetness are better shown by AM wave stimuli including specific two frequencies. We can conclude that the selected frequency and realistic waveform should be used simultaneously in order to display softness and wetness.

D. Is fusion between realistic waveform and selected frequency effective?

Result of the section *C* is tested, i.e. it is tested if the AM wave by adding the realistic waveform and selected frequency is effective to display the texture or not. As a result, softness is better shown when 5Hz component is added to the realistic wave, whereas the wetness is better shown when the 200Hz component is added. It is shown that the fusion of realistic waveform and selected frequency is effective. Optimization of the ratio among real waveform, 5Hz component and 200Hz component is a topic for the future study.

IV. CONCLUSIONS

It is shown that the ultrasonic vibrator can be used to display precise surface geometry of various objects by use of amplitude modulation of ultrasonic wave representing the realistic surface geometry. It is also shown that subjects can feel the tactile stimuli to be similar to the realistic touch on various surfaces when the waveform is changed accordance with the velocity change when vibrator moves with the finger movement. In order to display softness and wetness, it is effective to use not only the realistic waveform but also selected waves.

Optimization of the waveform, development of a vibrator having large display area and small body, and consideration of the effect of squeeze film [8] should be topics for the future study.

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