Gradual Phase Shift to Suppress Noise from Airborne Ultrasound Tactile Display

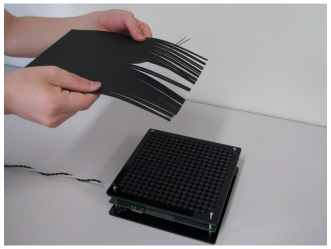

Figure 1: Ultrasonic device developed by the author. Paper strips are flipped up by acoustic radiation pressure of ultrasound.

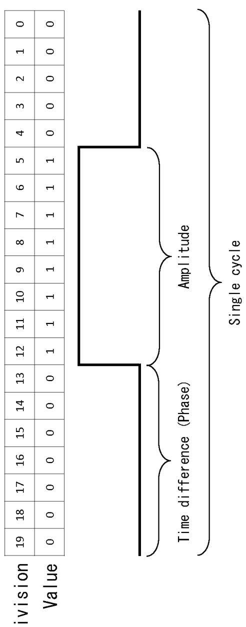

Figure 2: Single cycle with given time difference and amplitude.

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Abstract
It has been reported that ultrasound-based tactile displays radiate audible noise although ultrasound itself is inaudible. This noise possibly limits the application space. One noise source is the envelope of ultrasound for vibrotactile stimulation, which radiates audible sound based on the same principle of parametric speakers. The other noise source is the discontinuity of driving signals when the focal point moves around, which disturbs the periodic motion of the diaphragms and radiates crackle noise. This paper focuses on the latter noise source and proposes a control method to suppress it. The phases of the driving signals are updated in a step-by-step manner to avoid a sudden change of waveform. The noise level at 200 mm from the tactile display is reduced from 63 dB to less than 45 dB when the frame rate is 1,000 Hz. The proposed method contributes the society of the mid-air haptics.

Author Keywords
Non-contact tactile display; airborne ultrasound; radiation pressure; phased array focusing.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces; Haptic I/O.

Introduction
Ultrasound-based tactile displays have been studied these days [1][2][3]. This technology is based on a nonlinear effect of ultrasound, known as acoustic radiation pressure. The phased array focusing technique is used to generate a focal point of ultrasound to achieve high amplitude to press the skin surface sufficiently (Figure 1). The advantage of this technology is producing haptic feedback in air without wearing devices on hands. On the other hand, it has some drawbacks such as its small maximum force (up to several tens newton), line-of-sight requirement, required size of transducer array, unwanted grating lobes, and audible noise radiation.

The ultrasound-based tactile displays use ultrasound (usually 40 kHz) which is inaudible, however there are two sound radiation mechanisms that act as noise sources. One is the self-demodulation of the envelope of ultrasound [4]. Vibrotactile stimulation is produced by modulating the amplitude of ultrasound at the intended frequency. The modulation frequency is up to 1,000 Hz because of the perceptual characteristics of human tactile sensation, which is in the audible range

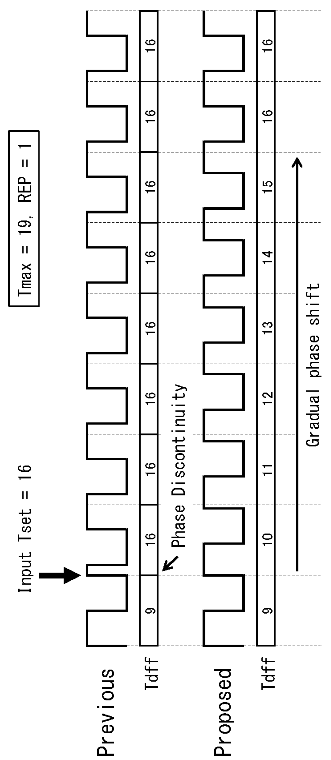

Figure 3: Previous and proposed phase control methods. Each cycle is divided into 20 divisions in this example. The phase (Tdff, time difference) is incremented every REP cycles.

(20-20,000 Hz). So vibrotactile stimulation is always accompanied by the noise of the applied frequency. One solution to eliminate this noise is to produce tactile stimulation by the movement of the focal point, instead of the amplitude modulation.

The other noise source is the discontinuity of the driving signals when the focal point is moved. The sudden change of the wave form of the driving signal disturbs the periodic motion of the diaphragm and an impulsive sound wave is radiated. This paper aims to reduce this noise by modifying the phase shift method.

Proposed Method: Gradual Phase Shift

The driving signal is a rectangular wave controlled based on given phase (time difference) and amplitude. Figure 2 shows an example where one cycle of the driving signal is divided into 20 divisions.

The proposed method is illustrated in Figure 3. The phase is incremented in a step-by-step manner to avoid sudden change of the waveform.

Experiment

The effectiveness of the proposed method was evaluated. The focal point was generated at random positions with various frame rates. More gradual phase update (REP ≥ 2) was more effective (Figure 4).

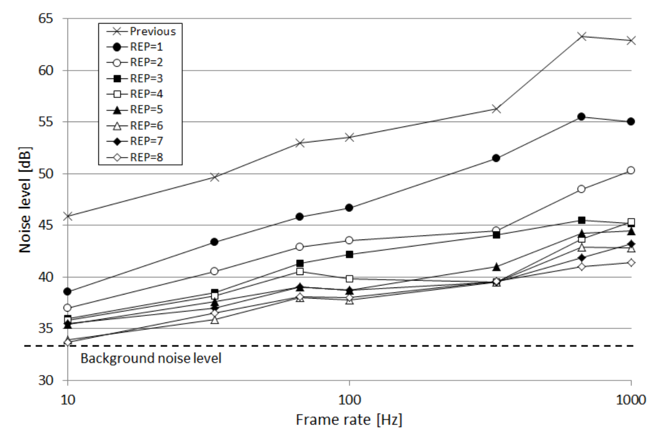

Figure 4: Experimental results.

References

1. Takayuki Hoshi, Masafumi Takahashi, Takayuki Iwamoto, and Hiroyuki Shinoda. 2010. Noncontact tactile display based on radiation pressure of airborne ultrasound. IEEE Transactions on Haptics 3, 3, 155-165. DOI: http://dx.doi.org/10.1109/TOH.2010.4
2. Keisuke Hasegawa and Hiroyuki Shinoda. 2013. Aerial display of vibrotactile sensation with high spatial-temporal resolution using large-aperture airborne ultrasound phased array. In Proceedings of World Haptics Conference (WHC), 2013, 31-36. DOI: http://dx.doi.org/10.1109/WHC.2013.6548380
3. Tom Carter, Sue Ann Seah, Benjamin Long, Bruce Drinkwater, and Sriram Subramanian. 2013. Ultrahaptics: Multi-point mid-air haptic feedback for touch surfaces. In Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13), 505-514. DOI: http://dx.doi.org/10.1145/2501988.2502018
4. Masahide Yoneyama, Jun-ichiroh Fujimoto, Yu Kawamo, and Shoichi Sasabe. 1983. The audio spotlight: An application of nonlinear interaction of sound waves to a new type of loudspeaker design. Journal of Acoustical Society of America, 73, 5, 1532-1536. DOI: http://dx.doi.org/10.1121/1.389414