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Midair Input-Output Interface Consisting of Depth Camera and Noncontact Tactile Display

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Abstract: A system is proposed which enables users not only to operate computers by moving their fingers in midair but also to feel touch feedback on their fingers. The system consists of a PC, a marker-less hand tracker for input, and a noncontact tactile display for feedback. The tactile display utilizes ultrasound to produce tactile stimulation from a distance. The principles of the tactile display are described and the developed prototype system is introduced.

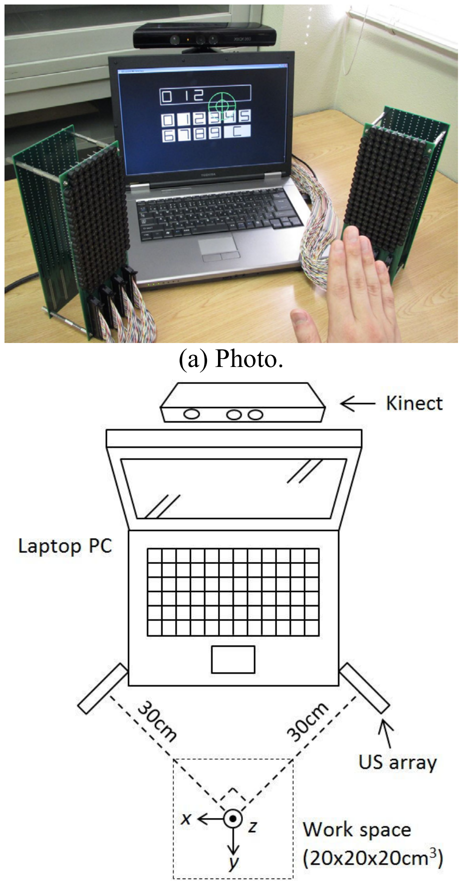
Keywords: User interface, tactile display, airborne ultrasound, acoustic radiation pressure.

1. INTRODUCTION

Recently, various technologies are developed which enable users to operate computers by moving their hands in air [1][2][3][4][5]. Such technologies would be used as interfaces with PCs, games, portable devices, digital signage, and so on. They are also promising in hospitals, food factories, and public spaces because the interfaces keep users' hands away from getting dirty. Currently, visual and/or audio feedback is usually provided. In [3], vibrotactile feedback is provided on the hand holding the portable device. For more intuitive feedback, it is preferable to provide tactile stimulation directly on the hand or finger associated with a cursor.

This paper proposes to combine an aerial input system with a noncontact tactile display (Fig. 1). The aerial input system uses a depth camera to track a user's hand. The tactile display utilizes airborne ultrasound to stimulate the user's hand tactually in midair [6].

This configuration is suitable for daily life because it demands no attachments on a user's hand for both of hand tracking and tactile feedback. For example, users can use the system with their hand being wet or dirty. They feel free to use it for a short time. They can use it simultaneously or alternately.



(a) Photo.

(b) Illustration (top view).

Fig.1 Developed aerial interface system.

2. NONCONTACT TACTILE DISPLAY

2.1 Acoustic radiation pressure

The noncontact tactile display is based on a nonlinear phenomenon of ultrasound: Acoustic radiation pressure. Assuming a plane wave, the acoustic radiation pressure P [Pa] is described as

$$P = \alpha E = \alpha \frac{I}{c} = \alpha \frac{p^2}{\rho c^2} \quad (1)$$

where E [J/m^3] is the energy density of ultrasound, c [m/s] is the sound speed, p [Pa] is the RMS sound pressure of ultrasound, and ρ [kg/m^3] is the density of medium. α is the constant depending on the amplitude reflection coefficient R at an object surface; $\alpha \equiv 1+R^2$.

2.2 Phased array focusing

The Phased Array Focusing technique is used to produce the radiation pressure perceivable by human skins. The focal point of ultrasound is generated by setting adequate phase delays of multiple transducers. Inthe previous study [6], it is confirmed that the force of 16 mN is produced when 324 transducers are employed. In addition, the focal point can be moved to an arbitrary position by controlling the phase delays.

It is theoretically derived that the spatial distribution of ultrasound generated from a rectangular transducer array is nearly sinc-function shaped [6]. The widths of the main lobe in two directions parallel to the sides of the rectangular (w_u [m] and w_v [m]) are written as

$$w_u = \frac{2\lambda R}{D_u} \quad \text{and} \quad w_v = \frac{2\lambda R}{D_v} \tag{2}$$

where λ [m] is the wavelength of ultrasound, R [m] is the focal length, and D_u [m] and D_v [m] are the side lengths of the rectangular array. Eq. (2) indicates that the spatial resolution and the array size are in the relationship of trade-off.

In the current prototype, the ultrasound transducers are arranged in a rectangular area whose D_u and D_v are 20 cm and 10 cm, respectively. The resonant frequency of the transducers is 40 kHz (i.e. λ =8.5 mm). Then, w_u and w_v are 2.6 cm and 5.1 cm, respectively, when R is set at 30 cm. Because the width of 5.1 cm is too wide to target a single finger, three fingers or a palm is the target of the prototype.

3. MIDAIR INTERFACE SYSTEM

3.1 Overview

A midair interface system (Fig. 1) was developed by employing the airborne ultrasound tactile display. The system consists of a laptop PC, the tactile display, and a hand-tracker. A circular cursor on the LCD of the laptop PC moves according to the position of a user's hand in X and Z directions. The size of the cursor changes according to the hand position in Y direction. The virtual touch screen is set at XZ plane (i.e. y = 0) and tactile feedback is provided when the user's hand is within the space where y ≤ 0. With this system, users can click, drag, draw, select, and so on, receiving not only visual but also tactile feedback.

Kinect [5] is used as a hand-tracker in this system. It is a depth camera based on an infrared pattern projected over its field of vision. The spatial resolutions are about 1 mm in all X, Y, and Z directions at a distance of 60 cm from the sensor. Currently, the nearest point and its vicinity are detected as a hand. An algorithm of bone estimation would be adopted to improve robustness of hand tracking.

The work space is a 20×20×20 cm^3 cubic area and it is divided into 5.0×5.0×12.5 mm^3 sub-areas. The center positions of the sub-areas are selectable as the position of the focal point. That is, the focal point moves among 40×40×16 discrete positions. While the amplitude of ultrasound is variable with PWM, it is tentatively fixed at the maximum value (i.e. 50-percent duty ratio).

3.2 Experiment

An experiment was conducted in order to examine how surely users could feel the virtual touch screen. Ten volunteers (between 21 and 30 years old, all male, and right-handed) took part in it. The subject was instructed to sit on a chair in front of the aerial-input system, move his hand toward the PC, and stop his hand when he felt tactile stimulation on his hand. Then the position of his hand was recorded. He repeated the trial 10 times. The focal point was generated at the center of the vicinal area around the nearest point. The modulation frequency was 200 Hz. The visual information was shut off by closing his eyes and the auditory information was blocked off by hearing a white noise with headphones.

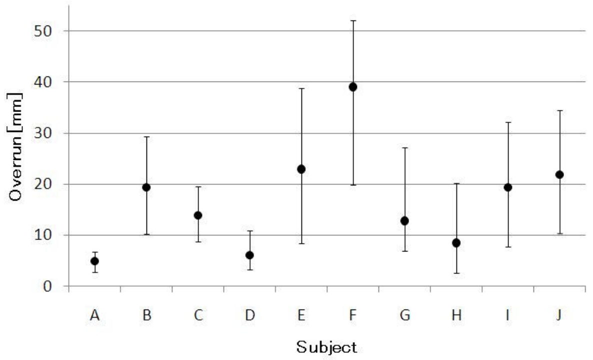


Fig.2 Experimental results. The black dot is the mean value for each subject. The bar connects the maximum and minimum values.

The results are shown in Fig. 2. The overrun (vertical axis) is the distance travelled along Y direction after the subject's hand passed the XZ plane. In the ideal case, the overrun would be zero because the virtual touch screen is set at the XZ plane. Fig. 2 shows the mean value as a black dot and the maximum and minimum values as both ends of a vertical bar for each subject. The mean value is the offset of position recognition and it can be compensated for each person. The difference between the maximum and minimum values indicates the degree of ambiguity. The offset and ambiguity averaged among the trials of all the subjects are 17 mm and 19 mm, respectively. That ambiguity implies that an interval wider than 19 mm is required when multi layered screen is reproduced.

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REFERENCES

[1] WiimoteProject, http://johnnylee.net/projects/wii/.
[2] aeroTAP, http://www.aerotap.net/?en.
[3] T. Niikura, Y. Hirobe, A. Cassinelli, Y. Watanabe, T. Komuro, M. Ishikawa: In-air Typing Interface for Mobile Devices with Vibration Feedback, Proc. SIGGRAPH 2010, Emerging Technologies, article no. 15, 2010.
[4] Mgestyk, http://www.mgestyk.com/.
[5] Kinect, http://www.xbox.com/kinect.
[6] T. Hoshi, M. Takahashi, T. Iwamoto, and H. Shinoda: Noncontact Tactile Display Based on Radiation Pressure of Airborne Ultrasound, IEEE Transactions on Haptics, vol. 3, no. 3, pp. 155-165, 2010.

(All URLs were last accessed on 10 June 2011.)