HORN: The Hapt-Optic Reconstruction

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1 Introduction

In this paper we propose a system that superposes a haptic sensation on a mid-air floating image based on ultrasonic standing waves. Conventional approaches of using airborne traveling ultrasounds could only apply weak pressure to the finger surface from a certain angle and thus a limited haptic sensation. Also, the ultrasounds generated air flow as a side-effect [Hoshi et al. 2009].

Here, the use of focused standing waves generated by the system shown in Figure 1 enables creating spatially varying acoustic pressures in all directions. In addition, this method suppresses the air flow. Such standing waves are employed to realize an elastic haptic feedback and to offer a rich haptic experience. Combined with ultrasonic beam steering and floating images, this system can display a virtual spherical gadget that is “pinchable” and “movable.” Thus, an intuitive human-computer interaction can be offered.

2 Principle

2.1 Mid-air Tactile Field

We utilize the acoustic radiation pressure accompanying the ultrasonic standing waves as a means of haptic feedback. When an object is placed between a node and an adjacent anti-node of the standing waves, a force that is proportional to the gradient of the square of time-averaged pressure is exerted to the object as in formula (1). Here, p is the acoustic pressure, $\bar{p^2}$ is the square of the time-averaged pressure, and γ is a constant that is determined by the density of the surrounding air. By focusing the standing waves from all directions, an intense single anti-node can be created. Since the force directs from anti-nodes to nodes, the user feels a central force around the anti-node as if actually pinching a three dimensional elastic sphere. Thus the system can provide an elastic haptic feedback [Whymark 1975; Inoue and Shinoda 2014].

$$F = -\gamma \nabla \bar{p^2} \quad (1)$$

Standing waves are created by using arrays of transducers aligned face to face as in Figure 1. Each face consists of 498 transducers (1992 in total). The transducers are driven so that a strong focal point is created within the cubic field surrounded by the transducers. The subjective feeling of the haptic sensation created in the middle is similar to that of pinching a cotton sphere. The overall field within the transducers is 35 cm × 30 cm × 27 cm.

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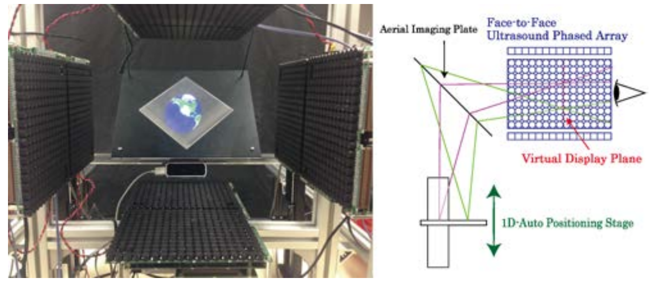

Figure 1: *(Left) The overview from the user’s point of view. (Right) The outline when looked from the side.*

2.2 Aerial Imaging

We employ the “Aerial Imaging Plate[Asukanet 2011],” a special glass plate that can reflect images as if it is floating in mid-air. The plate incorporates numerous micro-corner reflectors on the surface so that the image of an LCD display placed behind appears pinned in mid-air from any viewing angle.

The LCD display is mounted on an automatic positioning stage. This positioning stage adjusts the depth of the image plane.

2.3 Fingertip Tracking

We use the Leap Motion to conduct a marker-less fingertip tracking. The tracking data is used to update the focal point of the standing wave and the image plane of the Aerial Image.

3 Applications

Three applications are demonstrated. First, a virtual sphere that is “pinchable” is demonstrated. The virtual sphere moves along with the fingertips when it is “pinched,” and will explode when it is squashed. Second, a virtual wall that is impenetrable is demonstrated. The virtual wall exerts counter force to the fingertip when it tries to penetrate it. Third, a virtual earth globe that is scalable is demonstrated. The user can “pinch” the globe and scale it up and down depending on their fingertip motion.

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