Airborne Ultrasound Tactile Display

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1 Introduction

Currently, the importance of haptic interaction techniques gather much more attention with the progress of the computer graphics, the physical simulation and the visual display technologies. There have been a lot of interactive systems which aim to enable the users to handle 3D graphic objects with their hands (for example, see [Allard et al. 2007]). If tactile feedback is provided to the user's hands in 3D free space, the usability of those systems will be considerably improved.

One strategy to provide tactile feedback in 3D free space is to attach tactile displays on the user's hands. For example, Immersion Corporation developed CyberTouch [Immersion 2007] which features small vibrotactile stimulators on each finger and the palm to interact with objects in a virtual world with tactile feedback. However, this strategy inherently degrades tactile feelings due to the contact between the skin and the device occurring even when there is no need to provide tactile sensation.

Air-jet is another possible candidate. However, air-jet can not produce localized force due to diffusion. It also suffers from limited bandwidth. In addition, even if multiple air-jet nozzles are used, the variation of the spatial distribution of the pressure is quite limited.

The airborne ultrasound tactile display is designed to provide tactile feedback in 3D free space. The display radiates airborne ultrasound, and produces high-fidelity pressure fields onto the user's hands. without the use of gloves or mechanical attachments.

2 Principle

The method is based on a nonlinear phenomenon of ultrasound; acoustic radiation pressure. When an object interrupts the propagation of ultrasound, a pressure field is exerted on the surface of the object. This pressure is called acoustic radiation pressure. The acoustic radiation pressure P [Pa] is simply described as

$$P = \alpha E \tag{1}$$

where E $[\mathrm{J/m^3}]$ is the energy density of the ultrasound, α is a constant ranging from 1 to 2 depending on the reflection properties of the surface of the object. Eq. (1) means that the acoustic radiation pressure is proportional to the energy density of the ultrasound. The spatial distribution of the energy density of the ultrasound can be controlled by using the wave field synthesis techniques. With an ultrasound transducer array, various patterns of pressure field are produced in 3D free space. Unlike air-jets, the spatial and temporal resolutions are quite fine. The spatial resolution is comparable to the wavelength of the ultrasound. The frequency characteristics are sufficiently fine up to 1 kHz.

The airborne ultrasound can be applied directly onto the skin without the risk of the penetration. When the airborne ultrasound is applied on the surface of the skin, due to the large difference between the characteristic acoustic impedance of the air and that of the skin, about 99.9% of the incident acoustic energy is reflected on the surface of the skin. Hence, this tactile feedback system does not require the users to wear any clumsy gloves or mechanical attachments.

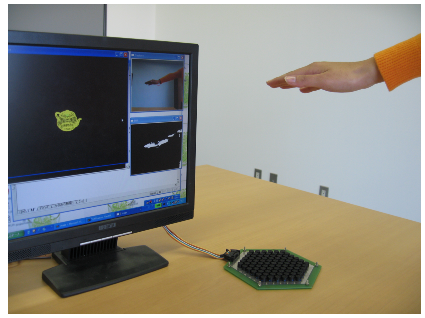

Figure 1: *The first prototype of the airborne ultrasound tactile display. Due to the ultrasound radiated from the transducer array, acoustic radiation pressure is exerted on the user's skin. Each transducer on the array is driven so that the emitted ultrasound produces a single focal point. The camera measures the position of the hand and the tactile feedback is provided when the hand is in contact with the virtual object.*

3 Application

Our airborne ultrasound tactile display is designed to provide tactile feedback for the users of 3D modeling software, video games and so on. Fig. 1 shows the first prototype system. The system is comprised of the airborne ultrasound tactile display and a vision-based hand tracking system. The tactile display exerts the radiation pressure on the user's hands when they "touch" 3D virtual objects.

The hand tracking system used in the prototype is a simple system comprised of a single camera. However, if the airborne ultrasound tactile display is combined with more sophisticated hand tracking systems like Grimage [Allard et al. 2007], it would be more practical haptic interaction system. It is also expected that by superimposing the acoustic radiation pressure onto the 3D graphic objects presented with stereoscopic displays, it effectively enhances the reality of the 3D virtual objects.

References

ALLARD, J., MENIER, C., RAFFIN, B., BOYER, E., AND FAURE, F. 2007. Grimage: markerless 3d interactions. In *International Conference on Computer Graphics and Interactive Techniques ACM SIGGRAPH 2007 emerging technologies*.

IMMERSION, 2007. Cybertouch. http://www.immersion.com/.

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