Compact Ultrasound Device for Noncontact Interaction

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Abstract. This paper introduces a compact device for noncontact interaction. It can push objects from a distance by utilizing focused ultrasound. The maximum output force at the focal point is 16 mN. The position of the focal point can be moved quickly and precisely. The device is small (19×19×5 cm^3), light (0.6 kg), and compact so that one can pick it up with one hand and install it at various places. This easy-to-use device would lead to a wide variety of applications.

Keywords: Noncontact interaction, Ultrasound, Acoustic radiation pressure.

1 Introduction

Noncontact interaction attracts a lot of attention of ordinary people and such a technology is expected to lead to a novel type of physical interface. Some tabletop systems with different principles are demonstrated in these years. Air jets are used in [1]. Three air jets surrounding an object moves it on a flat surface. ZeroN system [2] uses a solenoid coil attached on an XYZ stage. This system holds a spherical magnet in mid-air and moves it three-dimensionally. Ultra-tangibles system [3] utilizes focused ultrasound to control multi objects simultaneously. Four arrays of ultrasound transducer surround the workspace and move the objects two-dimensionally.

In a noncontact interaction system, actuators (e.g. air jets, solenoid coils, and ultrasound arrays in the systems introduced above) are usually built in the surrounding structures mainly because a large space is occupied by their own bodies, driving circuits, and wirings. It is not easy for other people, especially who are not familiar to electronics, to give it a try to use such actuators for their own issues. The application area of nonlinear interaction (including entertainments) would widely expand if the actuators become smaller, lighter, and more compact.

Our research group originally developed an ultrasound-based noncontact interaction device for the purpose of producing tactile stimulation from a distace [4]. The device pushes the surface of human skin by focusing airborne ultrasound. We call it "AUFD (Airborne Ultrasound Focusing Device)" hereafter. One of the most strengths of the AUFD is that it is noncontact and hence users do not need to wear or have stimulating devices on their hand. Additionally, the spatial and the temporal resolutions are both high and so various patterns of tactile feelings can be reproduced. The maximum output force is several dozen mN.

This paper introduces a compact device of AUFD (Fig. 1) smaller and lighter than the previsou one in order to explore its application other than tactile display. Its size and weight are 19×19×5 cm^3 and 0.6 kg, respectively.

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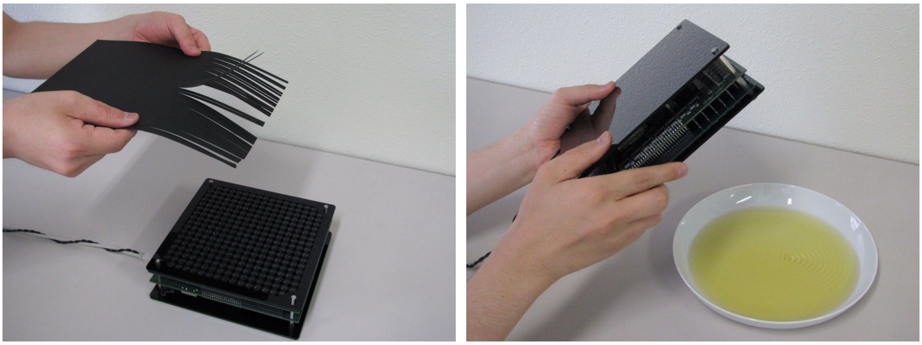

(a) Flipping up paper strips. (b) Vibrating water surface.

Fig. 1. Examples of possible applications of developed ultrasound focusing device

2 Principles

2.1 Acoustic Radiation Pressure

The acoustic radiation pressure, which is a nonlinear phenomenon of ultrasound, is utilized to push objects in midair. When an ultrasound beam is reflected vertically at an object surface, the surface is subjected to a constant vertical force in the direction of the incident beam. Assuming a plane wave, the acoustic radiation pressure P [Pa] is described as

$$P = \alpha E = \alpha \frac{p^2}{\rho c^2} \tag{1}$$

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 reflection coefficient at the object surface and α is equal to 2 in the case of total reflection. Equation (1) suggests that the spatial distribution of the radiation pressure P can be controlled by synthesizing the spatial distribution of the ultrasound p.

2.2 Phased Array Focusing

The phased array focusing technique is used to produce the radiation pressure up to several dozen mN. The focal point of ultrasound is generated by setting adequate phase delays of multiple transducers. In addition, the focal point can be moved to an arbitrary position by controlling the phase delays.

The spatial resolution and the array size are in the relationship of trade-off. It is theoretically derived that the spatial distribution of ultrasound generated from a rectangular transducer array is nearly sinc-function shaped. The width of the main lobe (*w* [m]) parallel to the side of the rectangular is written as

$$w = \frac{2\lambda R}{D} \tag{2}$$

where λ [m] is the wavelength, *R* [m] is the focal length, and *D* [m] is the side length of the rectangular array.

3 Prototype

The developed compact device (Fig. 1) consists of two circuit boards. One is an array board of ultrasound transducers and the other is a controller board including an FPGA and amplifiers. Both boards are 19×19 cm^2. They are connected electrically to each other by pin connectors instead of wirings.

285 pieces of ultrasound transducers (10 mm diameter, T4010A1, Nippon Ceramic Co. Ltd.) are arranged in a rectangular area whose *D* is 17 cm. As shown in (2), *D* is related to the resulting size of the focal point. The resonant frequency of the transducers is 40 kHz (i.e. λ = 8.5 mm). Then, *w* is 20 mm when *R* is set at 20 cm. The maximum output force is 16 mN (measured).

4 Possible Applications

4.1 Tactile Feedback

The AUFD provides noncontact tactile feedback in mid-air. It is suitable to be combined with aerial image displays [5] and aerial interface systems [6]. Besides, the stimulation of the AUFD moves finely (sub-mm resolution) and so it can reproduce handwriting strokes as tactile stimulation [7]. This kind of tactile stimulation may be utilized for transmitting non-verbal information, giving passwords more safely than displaying them on a screen, and showing characters instead of braille. Furthermore, it could be utilized to "make sound touchable" as demonstrated in [8].

4.2 Entertainments and Arts

The AUFD also has possibility to be used in the field of entertainments and arts. The output force is several dozen mN and so it can operate soft and/or light objects such as paper, smoke, water, particles [3], bubbles, balloons, etc. from a distance (Fig. 1). Mysterious and attractive effects would be demonstrated by using the AUFD.

It is easy to install the compact AUFD on the ceiling, the walls, etc. because it is compact. It is even possible to make it wireless if the USB module is replaced with a wireless module and a battery is mounted. This is optional and depends on user's electronic skill.

4.3 Measurements

The AUFD may contribute to develop a new measurement method in which the material surface is deformed or vibrated. It is used to deform the surface of elastic material and the deformation is measured by a laser displacement sensor to obtain the compliance distribution [9]. For another example, it is expected that the sound-based static electricity measurement [10] is expanded to 2D scan by employing the AUFD.

5 Conclusion

A compact ultrasound device for noncontact interaction was introduced. It is small and easy to pick up, bring, and install anywhere. The principles were explained and the possible applications were discussed.

It is expected that this compact device increases the user population and expands its application area. We are planning to lend the compact devices to researchers who want to give it a try to use the ultrasound-based noncontact interaction device.

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