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Three-dimensional Non-contact Manipulation by Opposed Ultrasound Phased Arrays

対向する超音波フェーズドアレイを用いた三次元非接触マニピュレーション

Takayuki Hoshi[1‡], Yoichi Ochiai[2], and Jun Rekimoto[23] ([1]Nagoya Inst. Tech.; [2]The Univ. of Tokyo; [3]SONY CSL)
星 貴之 [1‡], 落合 陽一 [2], 暦本 純一 [23] ([1]名工大, [2]東大, [3]SONY CSL)

1. Introduction

Mid-air non-contact acoustic manipulation [1] was reported by Kozuka *et al*. Two bolted Langevin transducers are arranged face-to-face and generate a standing wave of ultrasound beam between them. Small particles are trapped at the sound pressure nodes and also transported along the acoustic axis by controlling the phase difference between the transducers.

In this paper, we extend their achivement by employing airborne ultrasound focusing devices (AUFD) [2] instead of bolted Langevin transducers. Each AUFD generates a focal point of ultrasound at an arbitrary position based on the phased array focusing technique. The focal point acts as a ultrasound beam with a finite length, i.e., a focal depth of several centimeters. A localized standing wave is accordingly generated by the opposed AUFDs and traps small particles (**Fig. 1**). This method provides the following features.

(1) The small particles keep trapped even when the acoustic axis is horizontal because the AUFDs provide a sufficient amplitude of ultrasound.
(2) The particles can be manipulated not only along but also perpendicular to the acoustic axis according to the movement of the focal point.
(3) The work space is much larger then the previous researches because the ultrasound is focused and hence derivered further.

The rest of this paper consists of the detailed description of the AUFD and the demonstrations of the non-contact manipulation.

2. Airborne Ultrasound Focusing Device

The AUFD was originally intended to radiate a traveling wave and generate a non-contact force based on the acoustic radiation pressure (**Fig. 2**). In this paper, the same devices are used to make a standing wave and trap small particles at the nodes.

It is theoretically derived that the spatial distribution of ultrasound generated from a square transducer array is nearly sinc-function shaped.

Fig. 1 Levitation by opposed ultrasound phased array.

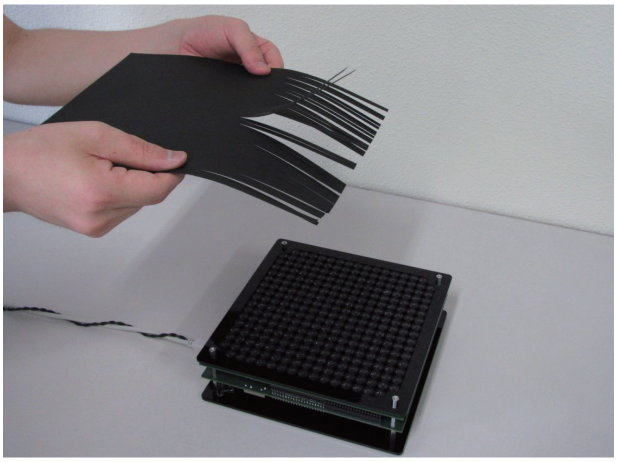

Fig. 2 Previous usage of AUFD [2]. Paper strips are flipped up by focused ultrasound.

The width of the main lobe (w [m]) parallel to the side of the square is written as

$$w = \frac{2\lambda R}{D} \quad (1)$$

where λ [m] is the wavelength, R [m] is the focal length, and D [m] is the side length of the square array. This equation indicates that the beam width and the array size are in the relationship of trade-off.

The specifications of the latest version of the AUFD are as follows. It is designed to be all-in-one and communicates with a PC via USB. The weight is 0.6 kg. The amplitude of ultrasound is 162 dB SPL at the center of the focal point with 285

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‡ star@nitech.ac.jp

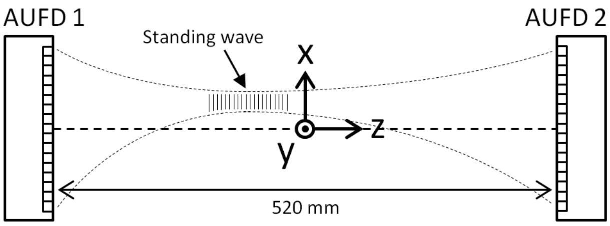


Fig. 3 Setup of non-contact manipulation system.

transducers (T4010A1, 40 kHz, 10 mm diameter, Nippon Ceramic Co., Ltd.) arranged within a 170×170 mm^2 square area. The size of the focal point *w* is, for example, 20 mm when the focal length *R* is set at 200 mm. The spatial resolution of the position of the focal point is 0.5 mm. The position can be updated at the rate of 1 kHz.

3. Manipulation by Localized Standing Wave

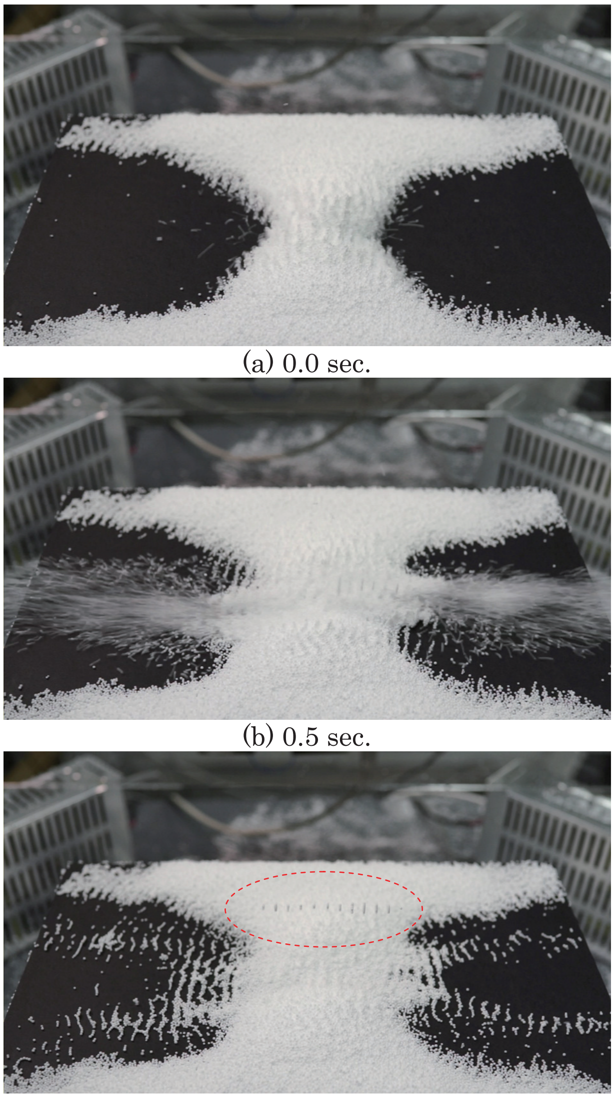
The system setup is shown in **Fig. 3**. Two AUFDs are arranged face-to-face with a distance of 520 mm. The middle point between the AUFDs is taken as the original point of the coordinate. The *z* axis is parallel to the acoustic axis.

Basically, a localized standing wave is generated when the AUFDs generate focal points at the same position. To be more detailed, it is experimentally found that an offset of focal length of several centimeters increases the stability and the total length of the standing wave. The offset was tentatively set at 50 mm in this paper. The amplitude of ultrasound was set at 70 percent of the maximum. It was because an airflow accompanying the ultrasound beam prevents particles from entering into the beam when the amplitude was stronger. The particles were expanded polystyrene and their diameter was 0.6 mm.

Three kinds of demonstration were conducted. First, the standing wave is fixed at the original point and the particles were sprinkled over it. Some of them were trapped at the nodes as shown in Fig. 1 and almost all of them kept trapped more than 1 minute.

Second, the position of the standing wave was moved along the *x*, *y*, or *z* axis. The movement along the *x* and *y* axes were more stable (i.e., little of the particle were dropped) than the *z* axis. It may be because most of the transducers change their phases simultaneously in the *z*-axis movement and that discontinuity flicks off the trapped particles.

Third, the particles were picked up when the standing wave passed through a mass of the particles. The mass was placed at (*x*, *y*, *z*) = (−100 mm, 0 mm, 0 mm). The standing wave started from (*x*, *y*, *z*) = (−110 mm, 0 mm, 0 mm) and moved up at a speed of 25 mm/s. Then the nodes were successfully occupied by the particles (**Fig. 4**).



(c) 1.0 sec.

Fig. 4 Pick-up sequence. The standing wave moves up through the mass of the particles.

4. Conclusion

In this paper, we introduced an extended method of non-contact acoustic manipulation. A localized standing wave is generated by two opposed ultrasound focusing devices. Small particles are trapped at the nodes and also moved three-dimensionally according to the position of the standing wave. The work space is a cuboid with sides of a few decimeters.

Future works include (1) optimizing the parameters, (2) evaluating the performance, and (3) exploring applications of the proposed method.

References

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