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Improvement of mid-air acoustic tweezers for non-contact particle picker

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***Abstract*—In recent years, there are some studies that report the method to levitate and manipulate a particle in air using ultrasonic transducers array. In previous study, we proposed the method to pick up a particle like a tweezers using ultrasonic waves and low-reflection stages. This method has the potential which increase applications of ultrasonic levitation. In this study, we designed and fabricated high-power ultrasonic transducers array and compared new and original array.**

***Index Terms*—acoustic levitation, transducers array, phased array, acoustic radiation force**

I. Introduction

In recent years, there are some studies that report the method to levitate and manipulate a particle in air using ultrasonic transducers array. Ultrasonic transducers array is the device that ultrasonic transducers are arranged and generates acoustic radiation force. Hoshi et al. fabricated ultrasonic transducers array and made it possible to manipulate particles at three dimension using opposite-faced array [1]. Asier et al. developed the method of particle manipulation at three dimension using only one-side array [2] [3] [4]. In our previous study, we proposed the method to pick up a particle in air like a tweezers using ultrasonic waves and low-reflection stages [5]. This method has the potential which increase applications of ultrasonic levitation. In this study, we designed and fabricated high-power ultrasonic transducers array and examined realizing more robust mid-air acoustic tweezers than previous devices.

II. Up-sizing hemispherical ultrasonic transducers array

Hemispherical ultrasonic transducers array is the device that ultrasonic transducers are arranged in hemispherical. The advantages of the shape of hemisphere are maximized acoustic pressure at a center of hemisphere and easily control of transducers for focusing acoustic wave. Fig.1 shows the model of original and newly designed arrays.

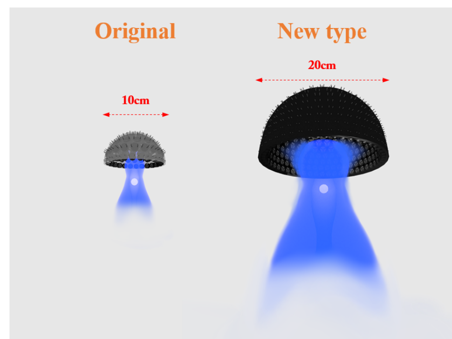


Fig. 1: Models of previous and new array

TABLE I: Comparison of two arrays

	Previous array	New array
Diameter [cm]	10	20
Number of transducers	80	438
Ultrasonic transducer	Murata, MA40S4S	Murata, MA40S4S

A. Design

We used 3D printer (Tiertime, UP300) for the hemispherical base. The diameter of the base is 20 [cm]. 438 ultrasonic transducers (Murata, MA40S4S) are attached to the base and connected in parallel. The diameter of ultrasonic transducer is 1 [cm] and the center frequency is 40 [kHz] ($\lambda \approx 8.5$[mm]). Max input voltage is 20 [Vp-p]. Table I shows the comparison of previous array and up-sizing array.

B. Phase control

The phase control method "Twin trap" is known to levitates a particle [2]. Twin trap forms two high pressure zone around target point and levitates a particle at the point. Twin trap emerges by inverting phases of half transducers in the case of hemispherical array. In this study, we apply phase control of transducers as shown in Fig. 2. In the figure, ϕ shows the difference from θ. This phase control can shift a focal point of twin trap in the direction perpendicular to the cross section of the hemisphere.

C. Measurement of sound field

Fig. 3 and 4 show the result of measured acoustic pressure distribution at the 25[mm]×25[mm] (1[mm] mesh) cross section near the center of the up-sizing hemispherical arrays. Measurement setup is shown in Fig. 5

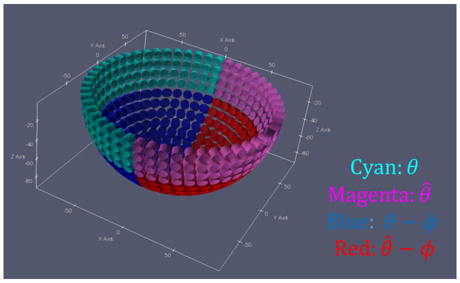
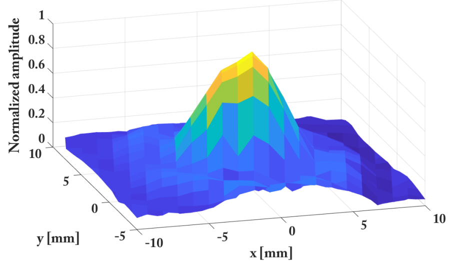
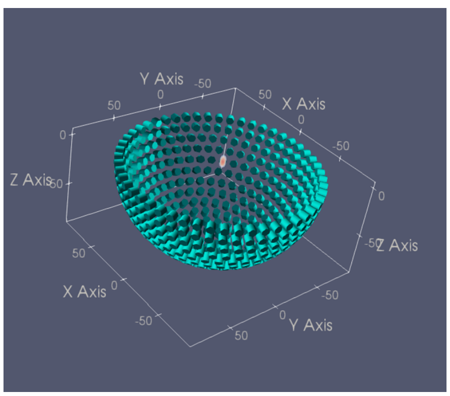


Fig. 2: Phase control of the array

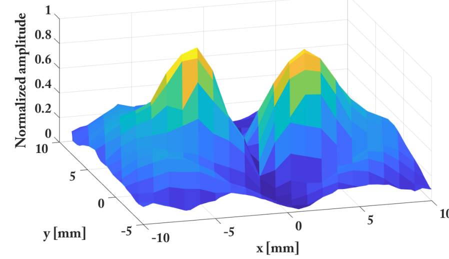


(a) Measured result

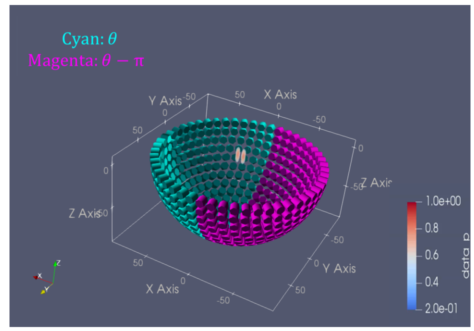


(b) Simulation

Fig. 3: Acoustic pressure distribution when all transducers are same phase.



(a) Measured result



(b) Simulation

Fig. 4: Acoustic pressure distribution when half transducers are inverted.

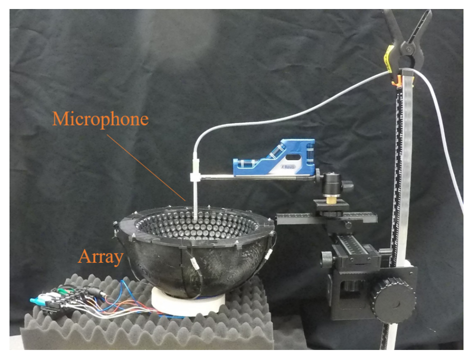


Fig. 5: Measurement setup

Fig.3 shows the measurement and simulation results when all transducers are same phase. We can see that the focal point is formed at the center like the simulation result. Fig4 is the measurement and simulation results that phase of half transducers are inverted. We can see the two high-pressure points, similar to the simulation result. In this way, a small particle can be held at low-amplitude point between two high-amplitude points.

III. Comparing up-sizing array and original

In previous study, we have conducted the experiments about mid-air acoustic picker using hemispherical ultrasonic transducers array having diameter of 10 [cm] [5]. In this section, we examine the usefulness of up-sizing ultrasonic transducers array by comparing new and original array.

A. Phase control experiment

By phase-control as shown in Fig.2 (or Fig.6 when using original array), levitated particle can be control up and down. We measured the position where particle levitates against each degree of ϕ (See Fig.2). The direction of the array is downward as shown in Fig.7. We used polystyrene sphere with a diameter of 3 [mm] as object of levitation particle. Input voltage of transducers was 10 [Vp-p] and the number of measurement at each degree (-195 to 330 by 15[degree]) was 3 times.

Fig.8 shows the result of the measurement. In the figure, $Distance$ means the distance from cross section of the hemi-spherical array and ϕ means the phase shift (See Fig.2). The error bar is the standard deviation. The levitated particle was controlled as ϕ shifted in the case of both arrays but interesting difference was appeared. In the case of original array, particle didn't levitate at over ϕ = 30 [degree]. This reason may be

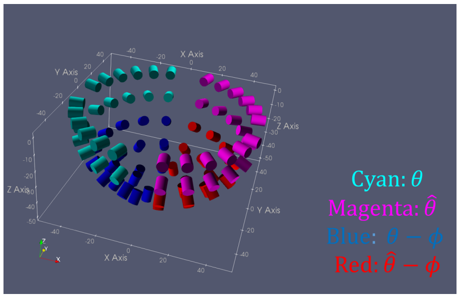


Fig. 6: Phase control of the array when using original array

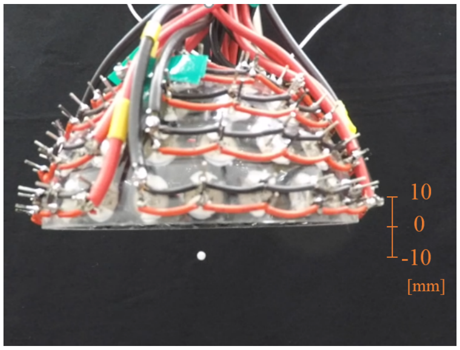


Fig. 7: The downward facing array and levitating particle

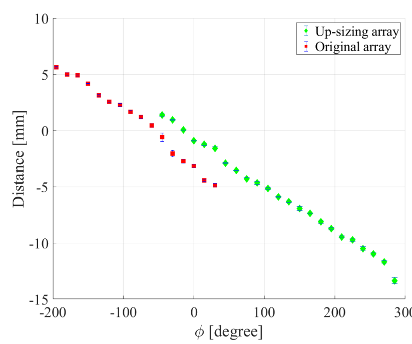


Fig. 8: The measured position where particle levitates at each degree

simply the difference in holding power of two arrays. In the case of up-sizing array, a particle didn't levitate at under ϕ = -45 [degree]. We could observe the particle was moving unstably like vibrating up and down at ϕ = -45 [degree]. This is due to acoustic streaming caused by very strong acoustic pressure.

B. Levitation power measurement using various particles

In this section, we compare the levitating forces of the arrays. In the experiment, we controlled the arrays in twin trap at ϕ = 0 (See Fig.2) and tried levitating various materials at different input voltages. The materials used for levitating particle was polystyrene sphere ($\approx$0.01[mg/mm^3]), wood chip ($\approx$0.5[mg/mm^3]), water droplet ($\approx$1[mg/mm^3]). The input voltage in experiment was set at 5, 10, 15[Vp-p], respectively.

Table II shows the list of experiment result. In the table, "able" and "unable" means that particle was levitated and

TABLE II: Result of levitating various materials

Polystyrene sphere

Voltage [Vp-p]	5	10	15
Original array	unable	able	able
Up-sizing array	able	able	able

Wood chip

Voltage [Vp-p]	5	10	15
Original array	unable	unable	unable
Up-sizing array	unable	able	able

Water droplet

Voltage [Vp-p]	5	10	15
Original array	unable	unable	unable
Up-sizing array	unable	able	able

Fig. 9: Levitating water droplet

not levitated, respectively. Fig. 9 shows the levitating water droplet. In general, we could say that up-sizing array increased the force of the levitation based on the results in Table. II: From the result using polystyrene sphere particle, the up-sizing array could levitate particle with low input voltage. Moreover, from the result of using wood chip and water droplet, the up-sizing array could levitate materials which original array couldn't. Additionally, shown in Fig. 10, acoustic picking up is also possible combining a low-reflected sponge stage. Here, the levitated particle is overlapped by focused laser.

IV. Conclusion

In this study, we considered up-sizing hemispherical ultrasonic transducers array and realizing more robust non-contact particle picker. The newly fabricated array was designed as a same way with original array which can generates sound field called "twin trap". In experiment, we could show the increase of the levitation power by up-sizing the array and newly make it possible to levitate droplet. In addition, the phenomenon "acoustic streaming" was observed when using up-sizing array with a high voltage input. We plan to conduct a further research for the future application using mid-air acoustic tweezers.

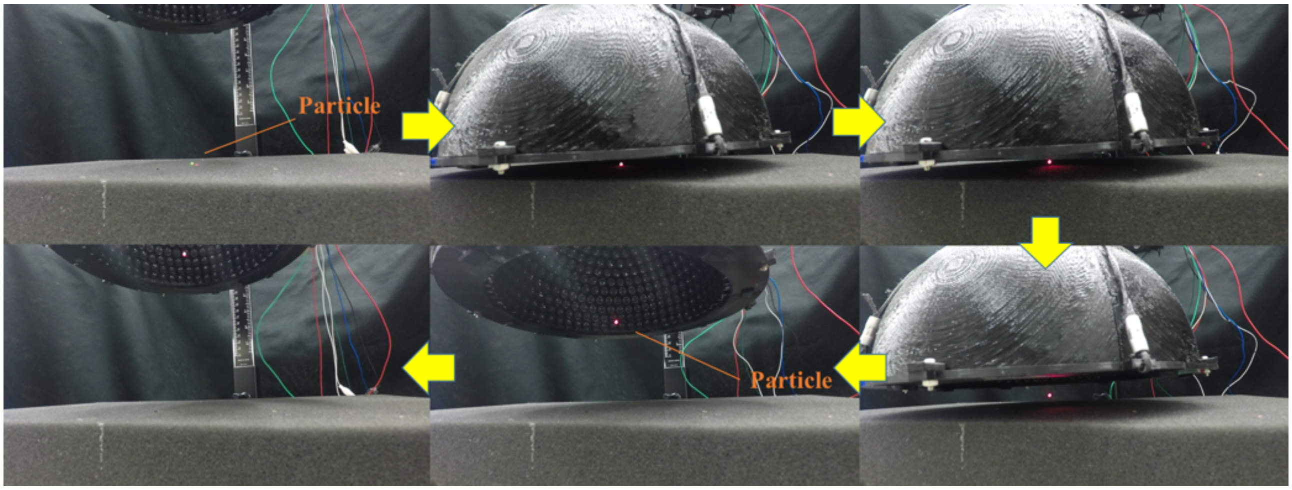


Fig. 10: Acoustic picking up

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