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Improvement of Mid-air Acoustic Tweezers for Non-contact Pick Up Based on Multi-channel Control

多チャンネル制御による空中音響ピンセットの高性能化

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1. Introduction

To date, there are some studies that report the method to levitate and manipulate a particle in air using acoustic radiation force with ultrasonic transducer array.

Levitation by acoustic radiation force can manipulate particles of various sizes and materials in various media such as water or water[1,2,3,4]. Therefore, applying to the fundamental tool is expected in manufacturing process, biology, and biomedicine.

Acoustic tweezers[4,5,6] use acoustic radiation forces to manipulate particles. Acoustic tweezers can be achieved relatively easily by using a hemispherical ultrasonic array[4]. Yamamoto and Okubo developed acoustic tweezers that selectively picked up with the hemispherical ultrasonic transducers array[4,5]. However, they can only trapped objects on a mesh table without sound reflection.

Then, we propose the multi-channel-controlled hemispherical ultrasonic transducers array and try to selectively pick up particles on an acoustically reflective stage. In this study, we try to optimize phases delay of multi-channel to pick up particles on a stage with reflection.

2. Method

2.1 Hemispherical ultrasonic transducers array

Fig. 1 shows so-called compact hemispherical ultrasonic transducers array, which is the device that ultrasonic transducers are arranged hemispherically. Using this array, a focal point is created in the center of the array and maximize the sound pressure there.

When half of the array is emitted in the opposite phase, the sound pressure at the focal point is cancelled out and a spot with high sound pressure is created to envelop the focal point. Thus, an object can be trapped in the focal point. This acoustic trap is called a twin traps. In this study, we perform mutli-channel control based on this method and improve mid-air acoustic tweezers.

2.2 Phase delay control

Particles can be trapped at an arbitrary position by minimizing the objective function of phase delay of ultrasonic transducers[5]. The acoustic levitation force $\boldsymbol{F}$ can be expressed by the following equation.

$$\boldsymbol{F} = -\nabla U, \qquad (1)$$

$$U = K_1(|p^2|) - K_2(|p_x|^2 + |p_y|^2 + |p_z|^2), \qquad (2)$$

$$K_1 = \frac{1}{4}V\left(\frac{1}{c_0^2\rho_0} - \frac{1}{c_p^2\rho_p}\right), \qquad (3)$$

$$K_2 = \frac{3}{4}V\left(\frac{\rho_0-\rho_p}{\omega^2\rho_0(\rho_0+2\rho_p)}\right), \qquad (4)$$

where U is the Gor'kov potential, p is the complex sound pressure, V indicates the particles volume, ω is the frequency of the emitted waves, v is particle velocity, ρ is the density and c is the speed of sound , subscripts 0 and p in equations denotes medium and the particle, respectively.

If there are N channels and M^j acoustic transducers that emits a constant frequency and amplitude for each channel, p is

$$p = \sum_{j=1}^{N}\sum_{l=1}^{M^j} e^{i\varphi^j} G^{jl}, \qquad (5)$$

where φ^j is the phase delay of the jth channel, G^{jl} is a complex number that is constant in this case. Therefore, the Laplacian of the Gor'kov potential can be expressed as

$$\nabla^2 U = f(\varphi^1, \ldots, \varphi^N). \qquad (6)$$

Consequently, forces must be convergence to trap particles. So the objective function O(φ^1,..., φ^N) is expressed as

$$\mathrm{O}(\varphi^1, \ldots, \varphi^N) = -\nabla^2 U \qquad (7)$$

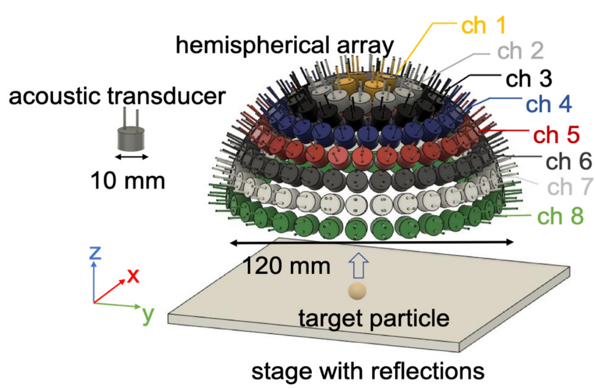

Fig. 1. Schematic diagram of the pickup with the hemispherical ultrasonic transducers array.

3. Simulation

3.1 Design and setting

We carried out simulation that gradually elevate the acoustic traps to assume pick up the particle on the reflective stage. We assumed to use 180 ultrasonic transducers (MA40S4S) which has a diameter of about 10mm and can produce ultrasonic waves of 40 kHz (about 8.5 mm wavelength).

Hemispherical array is 20 mm above the reflective stage. The stage is at $z = -20$. The sound field generated by reflective stage are calculated by the method of images and we used BFGS algorithm to minimize objective function.

3.2 Result

Fig .2 shows the simulation result. The colors represent the Gor'kov potential. The acoustic traps of the target are represented by the pink circle. The force works from high potential area to low potential area. The acoustic traps formed at the point where force is concentrated. Fig. 2 (c) and (d) suggest that the force is well focused and accurately formed acoustic traps.

Although the acoustic traps are created at the target point in Fig. 2 (a) and (b), there is another point where the forces converge in these figures. This point may make the particles be trapped in a different place from the target area.

4. Conclusion

We proposed the method for picking up the particle on the stage with acoustic reflection. The acoustic traps are formed at arbitrary position in the vertical direction by driving 8 channels of the hemispherical ultrasonic array and determining the phase delay of each channel by optimizing the objective function.

In this study, we estimate numerally the feasibility of mid-air acoustic tweezers to selectively pick up particles on an acoustically reflective stage by use of the multi-channel-controlled hemispherical ultrasonic transducers.

References

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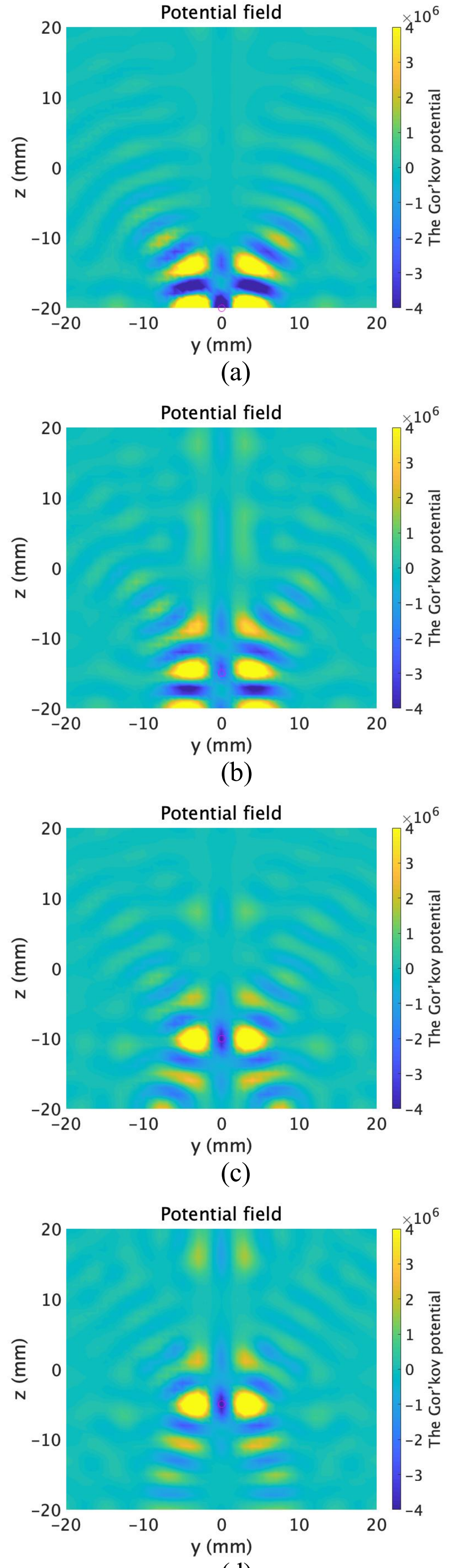

Fig. 2 Focus shift by 8 channel phase control