# 1J2-2

# Robust Design Using Adaptive Multi-channel Control for Mid-air Acoustic Tweezers

適応型マルチチャネル制御による空中音響ピンセットのロバスト設計

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## 1. Introduction

Remarkable developments of contact-less manipulation methods with ultrasonic transducer array have been reported recently. Levitation of a particle having a longer diameter than a wavelength was reported a few years ago[1]. And it was realized to manipulate some particles independently[2]. But stable manipulation with acoustic radiation force without environmental limitation (e. g., reflective sounds) has not been reported. An ultrasonic transducer array is capable of manipulating particles of various sizes and materials[3]. Therefore, it has a potential to be a promising fundamental tool for manufacturing process, biology, and biomedicine. Reducing environmental limitations of non-contact manipulation will increase the application possibility. In this research, we propose the method for adaptive non-contact single-axis manipulation near a reflective rigid stage.

## 2. Methods

A hemispherical ultrasonic transducers array is a device that ultrasonic transducers are arranged hemispherically. We developed the multi-channel hemispherical ultrasonic transducer array for adaptive non-contact manipulation. This array has the reverse polarity mode and the same polarity mode. In the case of the reverse polarity mode, we divide a hemispherical array into some blocks like a round slice and reverse the polarity of half the transducers in each block. Each block corresponds to each channel. In the case of the same polarity mode, we divide a hemispherical array into some blocks similarly, but the polarity of half the transducers in each block is the same. To optimize signals of each channel, we use the method derived from the sound reproduction technique with an inverse filter[4] as follows.

If there are $m$ transducers in the $j^{th}$ channel, we define a variable $g_{ij}$ as follows:

$$g_{ij} = \sum_{n=1}^{m} M_i^n \tag{1}$$

where $M_i^n$ is the propagator, and $n$ is the number of transducers.
Sound reflections are calculated using the image-source method, and are added to the propagator defined as

$$M_i^n = p_0 J_0(kr\sin\theta_i^n)\frac{1}{d_i^n}\exp\left(ik\, d_i^n\right) \tag{2}$$

where $p_0$ is a constant defined by the transducer power, $J_0$ is a zeroth-order Bessel function of the first kind, $k$ is the wavenumber, $k = \frac{\omega}{c_0}$, $r$ is the radius of the piston, $d_i^n$ is the distance between the transducer and the target object, and $\theta_i^n$ is the angle between the normal to the transducer and the target object. Then, we define matrix $\mathbf{G}$ as follows:

$$\mathbf{G} = \begin{bmatrix} g_{00} & \cdots & g_{0t} \\ \vdots & \ddots & \vdots \\ g_{c0} & \cdots & g_{ct} \end{bmatrix} \tag{3}$$

We define the target wave field as $H = [h_0, h_1, h_2 \cdots, h_c]$. We calculate the filter coefficient $W = [w_0, w_1, w_2 \cdots, w_t]$ by solving the following equation.

$$H = \mathbf{G}W \tag{4}$$

We solve this equation by the weighted least squares method using

$$W = (\mathbf{G}^*\boldsymbol{\phi}\mathbf{G})^{-1}\mathbf{G}^*\boldsymbol{\phi}H \tag{5}$$

where * denotes the Hermitian transpose, and $\boldsymbol{\phi}$ is the weight. Filtering the signal of each channel by the filter coefficient $W$, we optimize the phase and amplitude. The target fields $H$ was calculated by numerical simulation.

We use the reverse polarity mode to move up and down a particle in a position a little apart from a rigid stage. The same polarity mode is used when we move up and down it in close to a rigid stage. It is also possible to take the trapped object together with the array by raising the object to the center of the array.

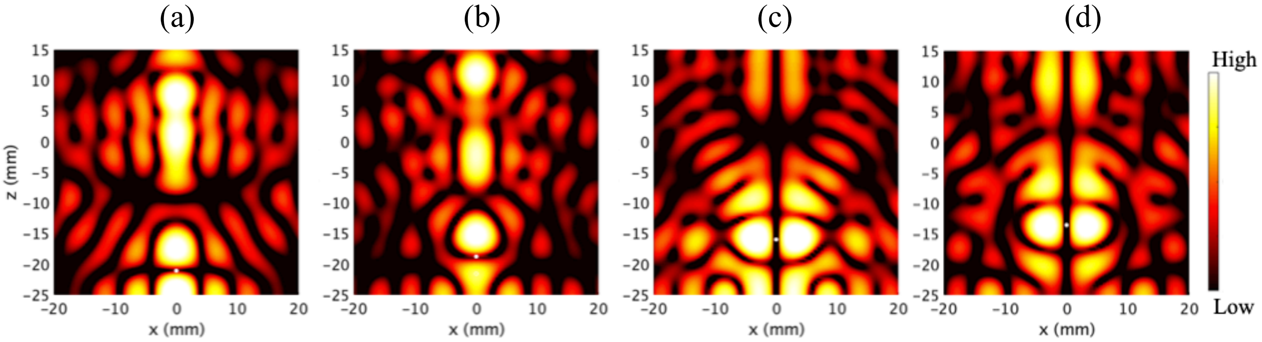


**Fig. 1** The wavefield on the vertical plane calculated by numerical simulation

**Fig.1** shows the acoustic pressure fields calculated by numerical simulation. **Fig. 1 (a) and (b)** show the case of the same polarity mode. **Fig. 1 (c) and (d)** show the case of the reverse polarity mode.

## 3. Experiment results

We manipulated a particle with hemispherical ultrasonic transducer array. **Fig.2** shows the proposed hemispherical ultrasonic transducer array with a diameter of 120 mm we used in the experiment. We used 180 ultrasonic transducers (Murata MA40S4S), whose diameter of the ultrasonic transducer is approximately 10 mm, with a center frequency of 40 kHz. We use all transducers to generate reverse polarity mode, while we use part of transducers to generate same polarity mode (**Fig. 3**), due to system limitations. We located the rigid reflective stage parallelly 25 mm below the array. We employed a about 2 mm diameter expanded polystyrene sphere as a target object. **Fig.4** shows manipulation results.

## 4. Conclusion

We developed the multi-channel hemispherical ultrasonic transducer array capable of switch two modes. And, we realized contactless manipulation with the array, whether there are reflections from a stage. In a future work, we perform to contact-less pick up a droplet with the hemispherical ultrasonic transducer array.

## References

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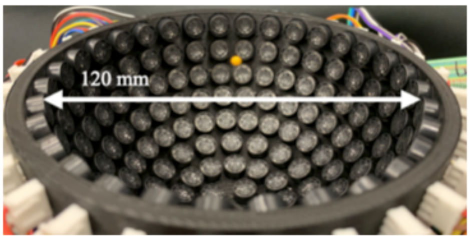


**Fig. 2** Hemispherical ultrasonic transducer array

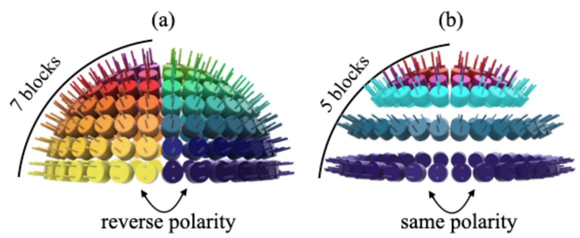


**Fig. 3** Sketch showing arrangement and polarity of transducers of each mode. (a) The reverse polarity mode (b) The same polarity mode


**Fig. 4** Photograph: the manipulation of a particle near the rigid stage combining both modes.