PhantomFields: Fast Time and Spatial Multiplexation of Acoustic Fields for Generation of Superresolution Patterns

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***Abstract*—Ultrasonic fields generated by phased arrays can be tailored to obtain a custom pattern of acoustic radiation forces. These force fields can pattern particles as well as be felt by the human hand, enabling applications for bioprinting and contactless haptic devices. The force fields can be switched orders of magnitude faster than the reaction time of the particles that it pushes or the human mechanoreceptors of touch. Therefore, a quick multiplexation in time or in space of different acoustic fields will be perceived as the average field. In this paper, we optimise the non-linear problem of decomposing a target force field into several multiplexed acoustic fields. We create averaged fields, PhantomFields, that cannot be created by a regular (unique) emission of an acoustic field. We improve accuracy by time multiplexation and spatial multiplexation, i.e. quick rotation of the emitters. These processes improve the resolution and strength of the obtained fields without the requirement of new hardware, opening up applications in haptic devices and 3D printing.**

***Keywords*—acoustic fields, phased-arrays, multiplexation**

I. Methods and apparatus

Phased arrays are used to generate ultrasonic fields. These arrays are composed of a certain number of acoustic transducers arranged as different geometrical shapes. For this work, a square array and a radial array have been used (Fig. 1). They have 1cm diameter ultrasonic emitters operating at 40 kHz.

The shapes and the limited number of transducers of these phased arrays lead to inaccuracies in the generated acoustic patterns when emitting a single field. To achieve higher resolution patterns without the need of new hardware, we introduce a different technique for their creation: the use of time and spatial multiplexation (Fig. 2). The multiplexation technique consists on creating various partial patterns and switch between them fast enough to achieve an improved average field in terms of resolution and strength. In the case of time-multiplexation, this combination is done in a reduced period of time, emitting one partial field in each instant. The spatial-multiplexation relies on the quick rotation of the phased array, creating one decomposed field for each array position.

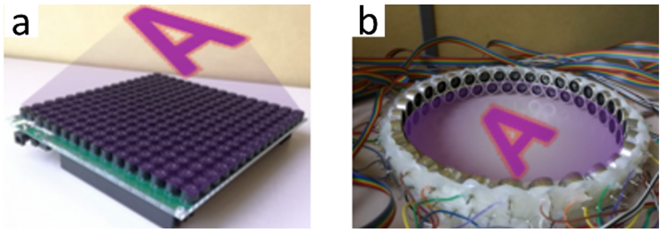

Figure 1. Phased Arrays: a) Square array of 16 × 16 transducers. b) Radial array of 64 transducers and 12cm radius.

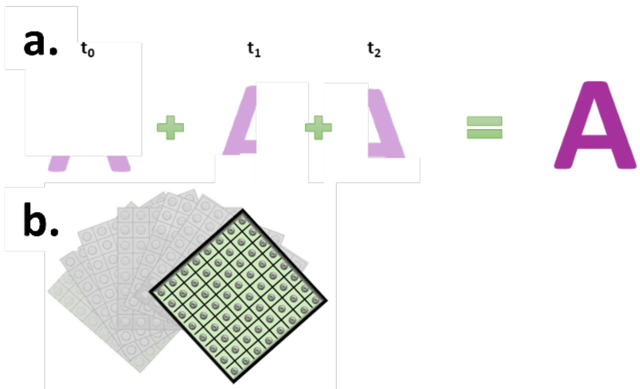

Figure 2. Multiplexing: a) Example of a pattern created by the time multiplexation technique. b) Example of the movement of the array for the spatial multiplexation technique.

II. Applications

Acoustic patterns can be benefitial for several applications, such as the manipulation of small objects (Fig. 3) and the creation of patterns of different matter (Fig. 4). Also, it opens up new opportunities for bioprinting and haptic devices, due to its relation with the tactile perception of acoustic patterns in the human skin.

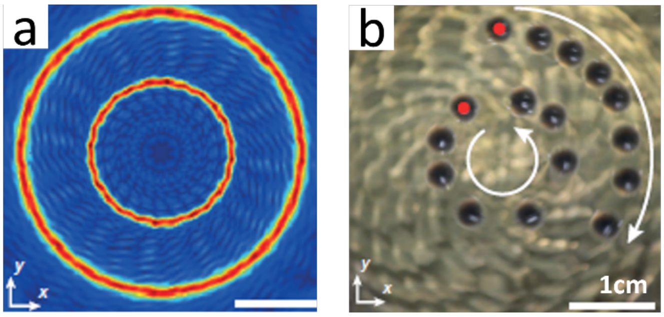

Figure 3. Manipulation of particles by acoustic fields [1]: a) Acoustic field amplitude. b) Two particles being moved by the acoustic field.

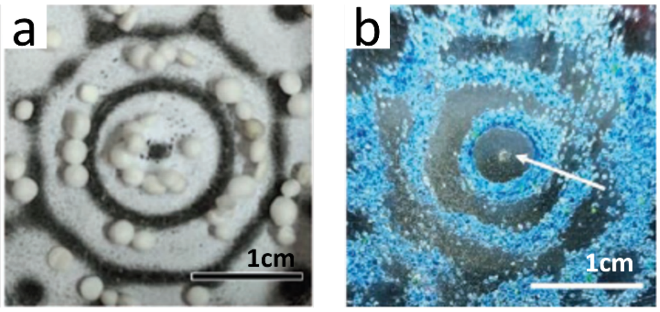

Figure. 4. Particle patterning [2]: a) Carbon-based conductive ink and polystyrene beads on paper. b) Sand and smaller dust fragments.

III. Main results

To optimise the non-linear problem of decomposing a target force field into several multiplexed acoustic fields, various simulations have been carried out. MATLAB has been selected as the engine to proceed with this optimizations and simulations. Various target patterns have been used, such as the ones shown in Fig. 5.

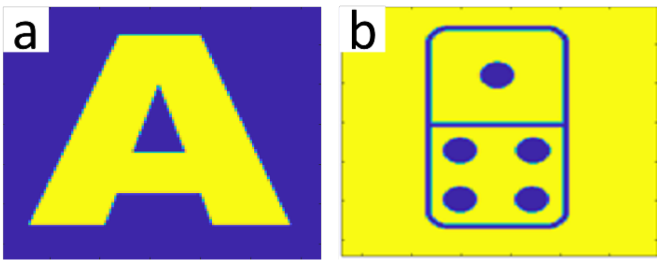

Figure 5. Example of patterns: a) 'A' and b) 'domino'.

In Figures 6 and 7, main results for two different patterns are shown. These patterns have $10cm \times 10cm$ in size. In both cases 16 multiplexations have been considered, which means that the resulting average field is composed of 16 multiplexed acoustic fields. For the 'A' pattern, a square array of 8×8 transducers has been simulated and, in the case of the 'domino' pattern, a radial array with a 12cm radius composed of 64 emitters.

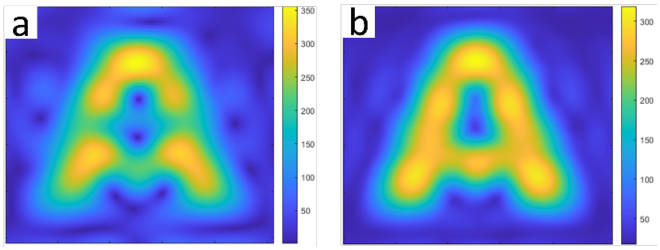

Figure. 6. Pattern 'A': comparison between a) unique emission and b) 16 multiplexed fields.

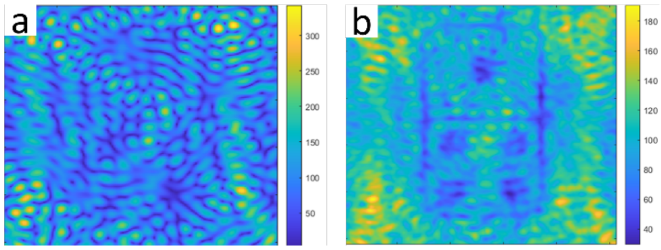

Figure 7. Pattern 'domino': comparison between a) unique emission and b) 16 multiplexed fields.

IV. Future work

In following steps, due to the promising simulated results, an experimental setup will be configured. In this way, the viability of the multiplexation techniques can be tested in a real environment, for instance, creating patterns on an oil bath.

Acknowledgment

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References

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[2] J. Shapiro, B.W. Drinkwater, A.W. Perriman and M. Fraser, "Sonolithography: In-Air Ultrasonic Particulate and Droplet Manipulation for Multiscale Surface Patterning", Advanced Materials Technologies, vol. 6, no 3, p. 2000689, 2021.