LeviPath: Modular Acoustic Levitation for 3D Path Visualisations

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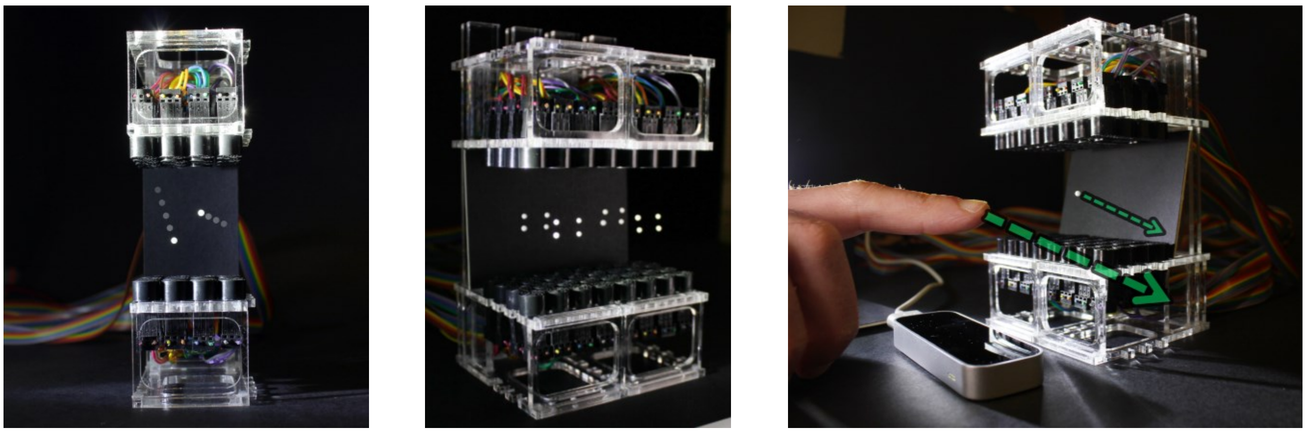

Figure 1: a) LeviPath uses two opposed arrays of transducers to levitate multiple objects across independent 3D paths; b) Interaction space can be increased by joining several LeviPaths together; c) Various devices can be used to interact with it.

ABSTRACT
LeviPath is a modular system to levitate objects across 3D paths. It consists of two opposed arrays of transducers that create a standing wave capable of suspending objects in mid-air. To control the standing wave, the system employs a novel algorithm based on combining basic patterns of movement. Our approach allows the control of multiple beads simultaneously along different 3D paths. Due to the patterns and the use of only two opposed arrays, the system is modular and can scale its interaction space by joining several LeviPaths. In this paper, we describe the hardware architecture, the basic patterns of movement and how to combine them to produce 3D path visualisations.

Author Keywords
Acoustic levitation; modular system; 3D paths; physical visualisations

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces.

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INTRODUCTION
Mathematicians have used physical representations of data since the 16th century. They calculated and assembled wood slices to represent and better understand 3D functions. Physical visualisations promote cognition and support visual thinking allowing humans to use an inherent skill set [8]. In a recent study Jansen et al showed that users preferred physical 3D bar charts as they were able to touch and point important parts of the chart with their fingers as well as rotate them naturally [5].

Even with the use of 3d printers and laser cutters, physical representations lack dynamicity to reflect changes in data. Shape-changing interfaces, such as inFORM [3], aim at solving this issue. inFORM consists of a 30x30 matrix of actuated columns that can individually change in height to create tangible dynamic height-fields. However, having solid columns can occlude some visualisations.

In this paper, we examine the suitability of acoustic levitation techniques to create dynamic physical visualisations. Levitation involves suspending an object in a stable position without solid physical contact. Thereby, objects can be placed in any 3D position of the interaction space enabling sturdy physical representations. Moreover, acoustic levitation offers additional advantages like direct reach-through interaction and the possibility of projecting on the object without occlusions. Several methods exist for contact-free levitation such as acoustic, optical, magnetic or quantum approaches [1]. Nonetheless, only some of them are suitable to exploit in an interactive context.

For instance, Zero-N [6] uses magnetic levitation to suspend a metallic ball and move it across the interaction space. It is possible to project on the ball and manipulate it. However, the levitated object needs to be magnetic, it is hard to scale the system for multiple objects and only the Z-axis position is controlled magnetically. The rest of the axes depend on mechanically-actuated components. Although the Universal Planar Manipulator [9] can magnetically move multiple objects, they are all resting on a table.

The use of acoustic levitation for HCI is exemplified by the system Pixie Dust [7]. In it, small objects are suspended and moved together using 4 opposed arrays of transducers employing a technique called focal lines. Although it allows several objects to be levitated, it does not enable individual control; all the objects move simultaneously in the same direction. Pixie Dust demonstrates the benefit of acoustic levitation for physical visualisations but also reveals the need for further improvements.

We present LeviPath, a modular system for levitating objects across 3D paths to represent functions, trajectories or other types of information (Figure 1). LeviPath has two main differences from previous acoustic levitation systems. Firstly, our system uses amplitude and phase manipulation to support controllable 3D levitation with only two opposed arrays of transducers. Secondly, our algorithm for controlling the position of the objects is based on the combination of basic patterns of movements. This allows to join several LeviPaths together to increase the interaction space. Additionally, different patterns can be used depending on the requirements of speed, manoeuvrability or power consumption.

LEVIPATH

LeviPath is our proposed modular system to levitate objects across a path for representing functions, trajectories or other information. LeviPath is composed of two opposed transducer arrays. Before describing the specific features of LeviPath and its working principle, it is useful to understand the principles behind acoustic levitation and the previous work in controlling a levitating object.

Principles of Acoustic Levitation

An acoustic transducer is a device capable of producing a sound wave with a certain amplitude and phase. By placing two transducers opposite to each other emitting with the same amplitude and phase, objects can be trapped and levitated in the space between, at the low pressure nodes of the standing wave. Furthermore, by changing the phase difference between the transducers the objects are moved from one transducer to the other [2]. With multiple transducers, two dimensional manipulation in air of solid or liquid particles can be achieved by either controlling the phase [10] or the amplitude of transducers [4]. Pixie Dust [7] goes further by using 4 arrays of transducers, orthogonally placed, to create three-dimensional movement.

LeviPath enables stable movement of multiple levitated objects in 3D space by manipulating both the phase and amplitude of subsequent opposed transducers. We demonstrate that only two opposing arrays are enough to levitate objects and perform all the movements needed for representing physical visualisations of 3D paths.

Movements

A pattern is the phase and amplitude of a group of transducers which are positioned above and beneath a levitating object at a specific time. These transducers create a standing wave between the top and bottom of where the object is. The transitions between several patterns move the standing wave and thus the levitated object along a 2D path contained in a plane parallel to the opposed arrays.

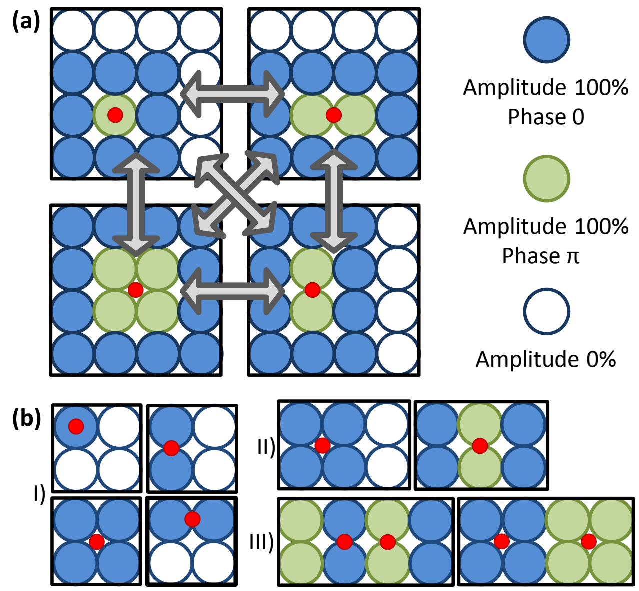

Figure 2: a) The key patterns can be interpolated between them in amplitude and phase. By doing so, the resulting position of the red levitating object also gets interpolated. b) Other patterns to levitate a single (I,II) or multiple beads (III).

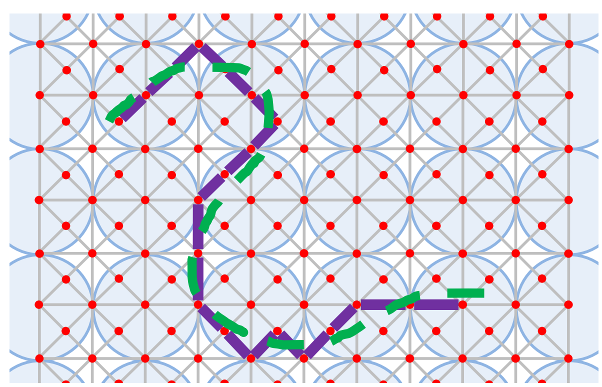

Figure 3: The red points represent the levitation points of the key patterns. Interpolating between adjacent pairs of key patterns, it is possible to move the objects along the grey lines. The desired 2D path (green) is adapted to the patterns possibilities resulting into the actual path (purple).

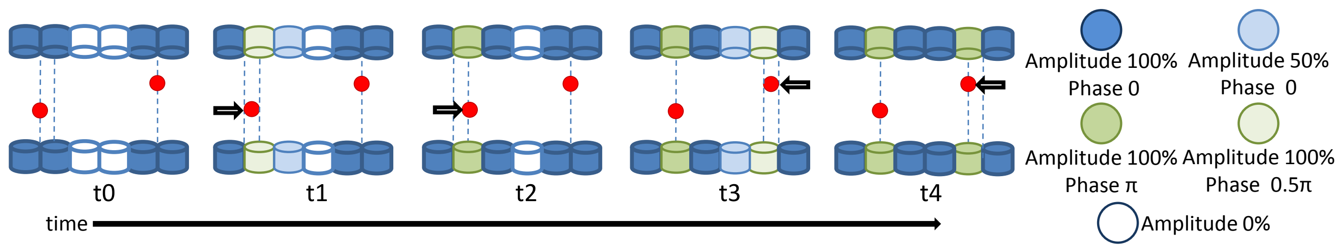

Figure 4: Individual movement of two beads in opposing directions. At time t0 both beads are stationary. At time t1, the phase of the second column of transducers increases from 0 to 0.5π and the amplitude of the third column of transducers increases from 0 to 50%; resulting in a movement of the left bead towards the centre. At time t2, a similar increase in phase and amplitude leads to continued movement for the left bead. At time t3 and t4, the same change occurs on the right side to move the second bead towards the centre. The step size in amplitude and phase determines the amount of movement.

A levitating position in the grid is more stable when the surrounding transducers have a phase difference of π with the transducers in the centre. Keeping this principle in mind, we designed our patterns to preserve this π phase difference along the required path. Consequently, we obtained improved stability resulting in faster movements of the levitated objects. The employed key patterns are illustrated in Figure 2(a). Only the status of one array is described since both top and bottom arrays use the same pattern. Figure 2(b) shows other patterns using fewer transducers, which are functional but less stable, as well as patterns for levitating multiple beads.

When we apply a constant phase difference between the top and bottom array, the bead can move perpendicularly to the arrays. Combining this 1D movement with the previous 2D movement, the levitated object can be moved across a 3D path. Given an input path, it can be decomposed into: a 2D path, controlled with the transitions between patterns (Figure 3); and a height variation, controlled with the phase difference between the top and bottom array.

LEVIPATH MODALITIES

LeviPath supports various modalities for levitating objects: single object, columns of objects and independent movement of two objects. The control of a single object has been described; however, between the top and bottom transducers, several acoustic nodes are created. Therefore, using the same approach, it is possible to place a column of beads and move them simultaneously along the same path.

Multiple levitated beads can also be moved across independent paths. As the patterns for moving one bead only occupy a certain part of the array, multiple beads can be controlled as long as the patterns do not intersect or overlap. This means that the levitated objects are always separated by at least the distance of one transducer.

In Figure 2(b), we show the key patterns that can be used to levitate two objects in different columns. By interpolating these key patterns, we can move the beads individually. As an example, in Figure 4 we illustrate a sequence of how two beads can be individually moved from the edges towards the centre with interpolations between key patterns. The step size in amplitude and phase can vary as required.

Whilst it is expected that there can be interferences from the transducers activated for levitating a second bead, their effective amplitudes decrease with distance and the patterns presented in Figure 2(a) have shown to produce stable movements.

IMPLEMENTATION

The current LeviPath system consists of two opposed arrays of transducers, a driver board and a PC (Figure 5). Each array holds 4x4 transducers (16 on top and 16 at the bottom). The MA40S4S transducers (diameter - 1cm, height - 8mm) generate a 40kHz wave with a directivity of 60º and 20 Pascals of pressure at a distance of 30cm. The separation between the two arrays was 43mm. Two LeviPaths powered at 16 volts and 0.5 amps consume a total of 8 watts.

The signals that control the transducers are generated by a custom driver board with 2 XMOS processors. This driver board transforms the information received from the PC into signals that make the transducers produce the desired amplitude and phase. The board calculates the signal for each transducer 20 times every period. Namely, it updates the signal at 800kHz giving a phase resolution of π/10 and 10 different values for the amplitude using Pulse Width Modulation.

The PC employs the algorithm described earlier to transform 3D paths into phases and amplitudes. The system also allows the control of the levitated objects with a keyboard, mouse or Leap Motion.

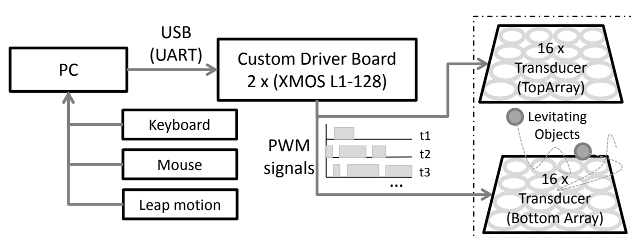

Figure 5: Hardware architecture of LeviPath. A PC issues orders to the XMOS driver board to move the bead across a 3D path. The board generates voltage signals to control the two opposed arrays.

LEVIPATH EVALUATION

Speed of the levitated objects

An experiment was conducted to measure the maximum speed of movement that can be applied to the levitated objects across two LeviPaths. We placed a different number of beads in the same column and moved them from the left side of the system to the right side (7 cm) five times. A trial consisted of moving a specific number of beads with a certain speed across the (7x5) 35 cm path. The success rate at a certain speed was measured as the number of times that all levitated beads completed the path without dropping.

The speed was controlled by a delay introduced before switching patterns. In this experiment, 10 pattern transitions represent 5mm of movement. Therefore, a delay of 1ms implies that the bead moves 5 mm in 10 ms; explicitly, 50 cm per second. Success rate for different speeds and amount of beads is shown in Figure 6. The slower the movement was, the higher the success rate. When levitating up to two beads, it is possible to maintain a success rate of 100% at a speed of 3 cm per second. We found this speed sufficient for interacting with the system comfortably.

For obtaining higher speeds, the strength of the levitating positions should be increased by using more powerful transducers or bringing the opposed arrays closer. Additionally, the algorithm should take into account inertia since the more problematic spots were the turning points. To increase position accuracy, the phase and amplitude modulation can be subdivided into more levels.

Characteristics of the Levitated Objects

With the presented hardware, we were able to levitate beads of 2 mm diameter and a density of 25 kg/m^2. The maximum weight of the levitated object is dependent on the levitation strength. The maximum size of the levitated object depends on the sound frequency; namely, the size should be smaller than half of the wavelength. Joining two LeviPaths increases the interaction space but it was always in the shape of a cuboid. However, it could be interesting to create curved paths or even joining LeviPaths in circular layouts.

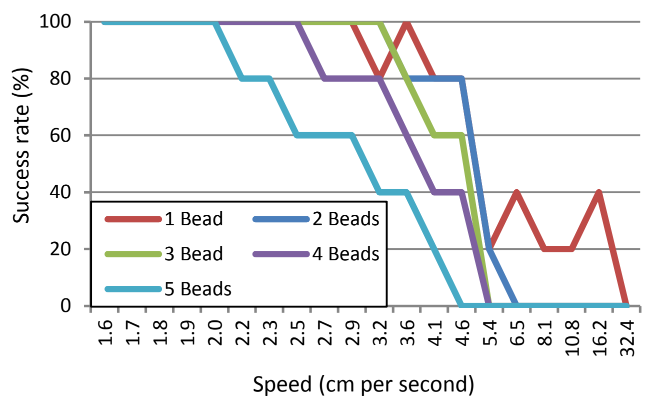

Figure 6: Success rate while moving several beads depending on the speed of movement.

CONCLUSION

A system to levitate objects across a 3D path has been described. LeviPath uses two opposed arrays of transducers and a novel algorithm to move objects based on the combination of key patterns. As a result, the system is modular since multiple devices can be joined to increase the interaction space. Additionally, multiple objects can move individually in different directions.

ACKNOWLEDGMENTS

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REFERENCES

1. Brandt, H. Levitation in Physics, Science, New Series, Vol. 243, No. 4889 (Jan. 20, 1989), pp. 349-355.
2. Courtney, C. R., Ong, C. K., Drinkwater, B. W., Bernassau, A. L., Wilcox, P. D. and Cumming, D. R. S. Manipulation of microparticles using phase-controllable ultrasonic standing waves, The Journal of the Acoustical Society of America, 128, EL195-EL199 (2010).
3. Follmer, S., Leithinger, D., Olwal, A., Hogge, A and Ishii, H. inFORM: dynamic physical affordances and constraints through shape and object actuation. UIST'13, 417-426.
4. Foresti, D., Nabavi, M., Klingauf, M., Ferrari, A. and Poulikakos, D. Acoustophoretic contactless transport and handling of matter in air. Proceedings of the National Academy of Sciences 110, 31 (2013), 12549-12554.
5. Jansen, Y., Dragicevic, P. and Fekete, J.D. Evaluating the efficiency of physical visualizations. SIGCHI, CHI '13, ACM (NY, USA, 2013), 2593–2602.
6. Lee, J., Post, R. and Ishii, H. 2011. ZeroN: mid-air tangible interaction enabled by computer controlled magnetic levitation. ACM UIST '11. (2011) NY, USA
7. Ochiai, Y., Hoshi, T. and Rekimoto, J. Pixie dust: graphics generated by levitated and animated objects in computational acoustic-potential field. ACM Transactions on Graphics (TOG) 33, 4 (2014), 85.
8. Moere, A.V. Beyond the tyranny of the pixel: Exploring the physicality of information visualization. In Information Visualisation. IV '08. (July 2008), 469–47.
9. Reznik, D., Moshkovich, E. and Canny, J. Building a universal planar manipulator. In Distributed Manipulation. (2000), (pp. 147-171). Springer US.
10. Seah, S., Drinkwater, B., Carter, T., Malkin, R., and Subramanian, S.. "Correspondence: Dexterous ultrasonic levitation of millimeter-sized objects in air." IEEE TUFFC 61, no. 7 (2014): 1233-1236.