Three-in-one: Levitation, Parametric Audio, and Mid-Air Haptic Feedback

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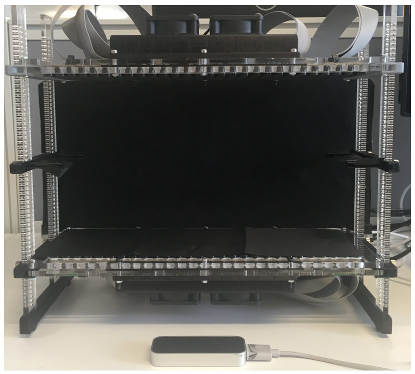

Figure 1: A portable and self-contained arrangement of ultrasonic transducers held together by a laser cut perspex and 3D printed parts. This rig is used to demonstrate levitation, parametric audio and mid-air haptic feedback simultaneously, and can receive user input through a Leap Motion controller.

KEYWORDS

Levitation; Ultrasound; Gestural controllers; Interface design;

ABSTRACT

Ultrasound enables new types of human-computer interfaces, ranging from *auditory* and *haptic* displays to levitation (*visual*). We demonstrate these capabilities with an ultrasonic phased array that allows users to interactively manipulate levitating objects with mid-air hand gestures whilst also receiving auditory feedback via highly directional parametric audio, and haptic feedback via focused ultrasound onto their bare hands. Therefore, this demo presents the first ever ultrasound rig which conveys information to three different sensory channels and levitates small objects simultaneously.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; **Auditory feedback**; **Gestural input**.

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Figure 2: A levitating bead traced a heart-shaped-path along a user-defined hand gesture. The images of a video were added together to produce this LeviPainting.

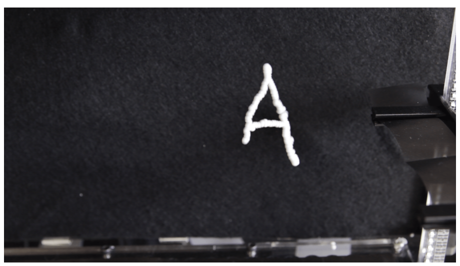

Figure 3: A levitating bead traced a letter-A-shaped-path along a user-defined hand gesture. The images of a video were added together to produce this LeviPainting.

INTRODUCTION

Since the advent of computers, scientists and Sci-Fi enthusiasts envisioned the fusion of virtual and physical world in an "Ultimate Display" [7]. This display will ideally be "a room within which the computer can control the existence of matter", shaping and reshaping matter to help us understand shapes of objects, enable see-through and grasp-through objects, and provide multi-sensory feedback to enhance the experience. One possible approach towards such a display is facilitated by ultrasound. Ultrasound enables levitation of multiple different particles (e.g. polystyrene beads, liquid drops) which are computer-manipulated to display different shapes in mid-air [5]. Further, using similar ultrasonic phased arrays, highly directional and steerable auditory feedback (i.e. parametric audio) [6] as well as haptic feedback [1] can be generated.

DEMO CONTRIBUTION

This demo paper presents for the first time ever a multimodal interaction (visual, auditory, and tactile) where the user controls the in-air levitating particles with hand gestures. Specifically, the ultrasonic levitation rig shown in Figure 1 presents directional auditory feedback to the gesture interaction and tactile feedback to enhance the sense of agency and improve user experience while enabling a much broader area for applications than was possible until now.

BACKGROUND

Ultrasound can be used for a multitude of interactive applications and is becoming more accessible to designers and researchers through projects like Ultraino [4] and companies like Ultrahaptics Ltd.
Levitation. Acoustic waves can levitate particles of a wide range of sizes and materials [2]. There are many ways of achieving this, including the generation of acoustic standing waves such that particles can 'sit' on the nodes of the waves, or acoustic traps which apply radiation forces to particles enabling them to levitate. The latter requires an electronically controlled phased array of ultrasonic transducers which allows for more stable and advanced manipulation of the levitated particles [4].
Parametric Audio. This is achieved by appropriately pre-distorting and modulating an audio signal onto an ultrasonic carrier [6]. Propagation in air causes demodulation of the compound signal which 'spills out' as audible sound along an ultrasound beam. It is possible to electronically steer the ultrasonic beam and thus the audible signal in a desired direction.
Ultrasonic Haptics. Focused sound can also exert pressure against the skin, enabling non-contact haptic feedback [1, 3]. This pressure is too weak to be perceived, but feels like vibration when the amplitude is modulated at a frequency within the range of vibrotactile perception (e.g., turning it on and off at 200Hz), or when the focus is moved along a lateral or closed path at high speeds.
Multimodal. There have been numerous example use cases of the above technologies in HCI, most

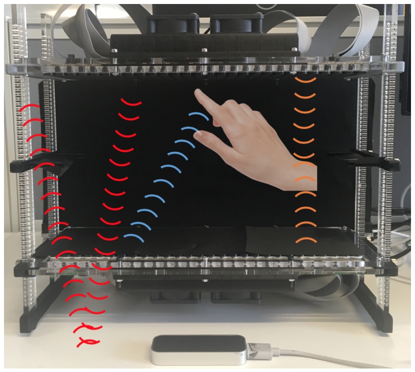

Figure 4: The ultrasonic rig is divided into different parts to support the three functionalities. The right half is the levitation area where small objects can be manipulated in space via acoustic traps (orange). The top left transducer array is used to project a beam of parametric audio (red) onto the table such that it can get reflected into the user's direction. Bottom left transducer array produces the haptic feedback (blue). The user's hand is gesturing above the Leap Motion device (infront of the rig) and receives feedback about interaction onto the index finger.

often using 40kHz ultrasound. Recent advancements in software and hardware have allowed combinations of the three, typically in pairs of two, to be demonstrated simultaneously. Here, we present an example of all three technologies working in parallel to create a multimodal interactive experience.

DEMO SET-UP

Two Ultrahaptics UHEV2 devices comprising of 9×28 ultrasonic transducers each have been placed in a sandwich arrangement with transducers facing each other to create the desired acoustic fields and cancel any undesirable opposing pressure forces (Figure 1). Everything is held together by a laser cut perspex and 3D printed frame ($L39 \times D18 \times H31$ cm) that includes additional USB-powered fans for cooling and has adjustable height. The two transducer boards are spaced about 16.5 cm from one another and are cabled together such that synchronization of top and bottom boards is achieved, which is necessary for stable levitation. The enclosing volume of about $L28.8 \times D9.1 \times H16.5$ cm is what we will refer to as the *levitation space*.

We track the user gesture with a Leap Motion Controller (www.leapmotion.com). The path of the index finger executed inside of the Leap Motion's interaction area is translated into the levitation space and the input signal is further smoothed out by a moving average filter. The sides of the rig are fitted with small platforms made of acoustically transparent material (Saati Acoustex B003HYD) enabling the easy loading of the to-be-levitated polystyrene beads (approx. 2 mm).

To achieve simultaneous levitation, parametric audio and haptic feedback, we dedicate different parts of the rig to particular purposes (Figure 4). Namely, while the right half (top and bottom) of the rig is dedicated to levitation (effectively halving the levitation space), the top left is used for parametric audio, and the bottom left for haptic feedback. The top left 9×14 transducer array projects a beam of parametric audio downwards and at an angle of 30 degrees onto the table on which the rig stands. The beam then reflects and can be heard by the user if they are standing at the right height and position such that their head is in the reflected parametric audio beam. Meanwhile, the bottom left 9×14 transducer array focuses ultrasound onto the users hand which is being tracked by the Leap controller. In this way, we minimize interference and corruption between the different acoustic fields. It is easy to switch left for right functions dynamically.

INTERACTIVE DEMO

To exemplify the capabilities afforded by the multimodal levitation rig described previously, we present an interactive function we call *LeviPaint* that uses a levitating particle as a paint brush in air. To accomplish this, the levitating bead follows a user-defined path, and if this path is captured through a long exposure image, a *LeviPainting* is created (see for example Figures 2 and 3).

In order to create a LeviPainting, users will be guided through the three phases of the planned interaction. Phase 1 consists of the user drawing a shape in mid-air using their index finger above the

Leap Motion hand tracker. On entrance of the hand into the interaction area, the rig produces a short high-pitched beep sound therefore prompting the user that their hand is being tracked. This indicates the system is ready for input. On hearing that tone, the user starts drawing and the system records their motion. Moreover, the rig projects haptic feedback onto the user's index finger. Once the user's hand exits the interaction region and the Leap loses the hand, the system progresses to phase 2. In phase 2, the rig transports the bead from the loading platform towards the centre of the levitation space, and then replays the recorded motion with the bead tracing out the same path as the user's hand. The bead motion is then traced back in reverse and then the bead is dropped. During levitation flight, an audio track is also played from the top left part of the rig, however is perceived as if coming from under the table due to the reflection described previously. A DSLR camera is used to take a long exposure photograph (approx. 30 seconds) of the moving levitating particle on a dark background to capture its trail. Finally, in phase 3 the LeviPainting is produced and displayed on an LCD screen nearby. The whole interaction takes about 1 minute and requires 1 more to reset for the next user.

CONCLUSION

Ultrasound offers a wide range of multimodal (audio-visual-haptic) opportunities for information displays. Not only can it levitate and manipulate small objects in real-time to draw different shapes in mid-air, but it can also present haptic and audio feedback to the user through the same ultrasonic hardware apparatus. Our demo presents the first ever compact and self-contained ultrasonic rig capable of these three technologies (levitation, mid-air haptics, parametric audio) simultaneously and therefore can encourage broad discussion about new HCI application areas. For instance, how can we scale this technology up to room-sized deployments; what kind of immersive applications are possible; can we communicate science in a new way; and can we create new and exciting art installations?

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REFERENCES

[1] T. Carter, S. A. Seah, B. Long, B. Drinkwater, and S. Subramanian. 2013. UltraHaptics: Multi-Point Mid-Air Haptic Feedback for Touch Surfaces. *UIST* (2013), 505–514. https://doi.org/10.1145/2501988.2502018

[2] E. Freeman, J. Williamson, P. Kourtelos, and S. Brewster. 2018. Levitating Object Displays with Interactive Voxels. In *PerDis '18*. ACM Press, Article 15. https://doi.org/10.1145/3205873.3205878

[3] T. Hoshi, M. Takahashi, T. Iwamoto, and H. Shinoda. 2010. Noncontact Tactile Display Based on Radiation Pressure of Airborne Ultrasound. *IEEE Transactions on Haptics* 3, 3 (July 2010), 155–165. https://doi.org/10.1109/TOH.2010.4

[4] A. Marzo, T. Corkett, and B. W. Drinkwater. 2018. Ultraino: An Open Phased-Array System for Narrowband Airborne Ultrasound Transmission. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* (2018). https://doi.org/10.1109/TUFFC.2017.2769399

[5] Y. Ochiai, T. Hoshi, and J. Rekimoto. 2014. Pixie Dust: Graphics Generated by Levitated and Animated Objects in Computational Acoustic-potential Field. *ACM Trans. Graph.* 33, 4, Article 85 (July 2014), 13 pages. https://doi.org/10.1145/2601097.2601118

[6] F. J. Pompei. 1995. *Sound From Ultrasound: The Parametric Array as an Audible Sound Source i-A*. Technical Report. http://sound.media.mit.edu/%7Ebv/

[7] I. Sutherland. 2001. The Ultimate Display. *Proceedings of the IFIPS Congress 65(2):506-508. New York: IFIP* 2 (01 2001).