DOI: 10.61782/fa.2025.0076

FORUM ACUSTICUM EURONOISE 2025

ACOUSTIC LEVITATION IN AIR: NOVEL TECHNIQUES AND APPLICATIONS

Asier Marzo[1]*
[1] Department of Computer Science, Universidad Publica de Navarra, Spain

ABSTRACT

Acoustic levitation can hold different material in mid-air. Typically, an emitter and an opposed reflector form a standing wave. Millimetric particles significantly smaller than the wavelength can be trapped in the nodes of the standing wave. Despite the limitations on particle size, the diversity of supported materials enables multiple applications. Metals, liquids, gases, plastics or small living beings can be trapped with acoustic levitation. Some applications are contactless spectroscopy or the study of crystallization of levitated samples. In this presentation, novel techniques beyond standing waves will be presented such as acoustic vortices or bottle beams that provide positional and orientation control on the levitated particles. We will highlight emerging applications in additive manufacturing, particle agglomeration, aerosol control, patterning, or pick and place of fragile samples. Finally, we will present some opportunities to get started in mid-air acoustic levitation using devices that can be built at the lab or even at home with off-the-shelf components.

Keywords: acoustic levitation, radiation force, acoustic traps, beamforming

1. INTRODUCTION

Sound can held in mid-air small particles made of different materials [1]. Acoustic levitation in air typically uses an ultrasonic emitter and an opposed reflector [2] to create a standing wave, with particles levitating at its nodes. Other setups use two opposed emitters [3], an array of emitters and reflectors to enable transportation, and recently, phased-arrays [4] are used to levitate multiple particles independently [5]. Trapping on a standing-wave node limits the particle size to half-wavelength, and emitters should be around the particle. Recent research showed that single-beams can trap particles [6, 7] and that particles larger than the wavelength can be trapped in vortices [8] and special acoustic bottles [9].

More advances can be found in acoustic levitation reviews: general [10, 11], liquids [12], biomaterials [13], airborne chemistry [14] or soft matter [15].

2. HOMEMADE LEVITATORS

Lab equipment can be expensive and hard to access, thus limiting exploration and accessibility to acoustic levitators. In the past decade, various levitators that can be built with off-the-shelf components have been shown and successfully used for research activities. Homemade devices are not as accurate or powerful as lab equipment, but they are available to a wider range of researchers, including hobbyists and schools.

TinyLev [16] is a single-axis standing-wave levitator, it has two opposed bowls made of 36 emitters each. The emitters are off-the-shelf $40\,\mathrm{kHz}$ transducers that are arranged around a sphere of 13 cm diameter. This gives the setup a natural focus, and can levitate liquids and samples of densities up to $2.4\,\mathrm{g/cm^3}$ and $3\,\mathrm{mm}$ diameter. The electronics are simplified and use an Arduino Nano and a motor driver (L298N). The levitator and some levitated samples are shown in Figure 1. Modifications of TinyLev make it more compact (Mk3 [17]) or able to levitate denser particles (MightyLev [18]).

SonicSurface [19] is an integrated $40\,\mathrm{kHz}$ phased-array of 16×16 emitters, with individual control of phases

**Corresponding author*: asier.marzo@unavarra.es.

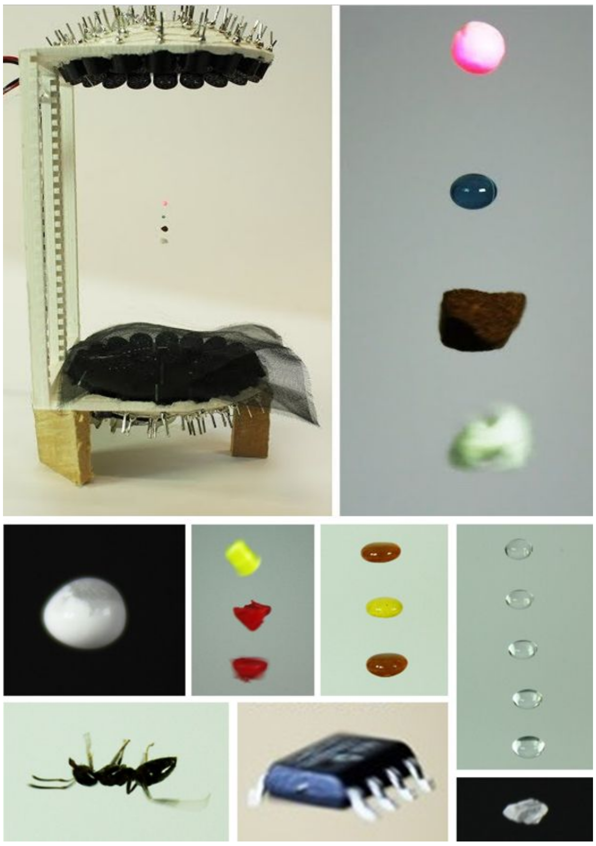

Figure 1. TinyLev is made of two opposed bowls with 36 ultrasonic emitters each, the bowls have a separation of 10 cm. Bottom) some levitated samples, left to right: titanium dioxide in water, plastics, ketchup and mustard, water, ant, integrated circuit and salt.

(see Figure 2). It has been used in various research projects [5, 20–22]. Other open phased-arrays have been published [23–25].

3. EMERGING APPLICATIONS

Apart from the applications referenced in the introduction, we describe some recent explorations that go beyond containerless and contactless processing.

Aerosols falling into a substrate get patterned along the high-amplitude areas where an acoustic field is applied [26]. The variety of aerosols enables application in bio-fabrication but also for printed electronics when conductive powder is mixed with the liquid medium.

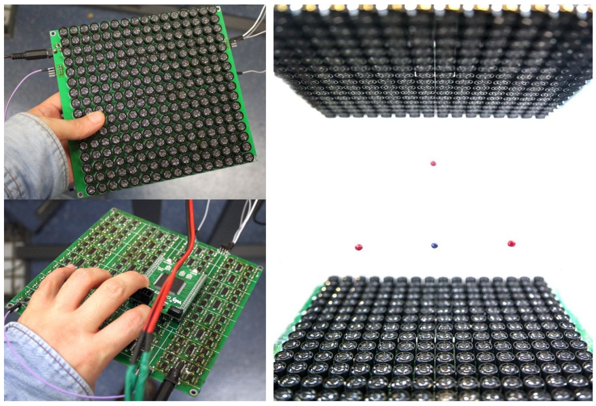

Figure 2. SonicSurface is an integrated phased-array with 256 emitters of 1 cm-diameter. It can levitate multiple particles and control them individually.

LeviPrint [20] explores the levitation of droplets of glue, solid particles and elongated thin objects to build structures in a contactless way. Traditional standing waves can hold droplets and spherical particles whereas other fields are optimized to held in position and orientation elongated sticks. The assembly can be done without touching the pieces to avoid cross-contamination, and the structure can be built inside a container as long as there is a small aperture for the parts to enter. Figure 3 shows a structure built with levitated sticks.

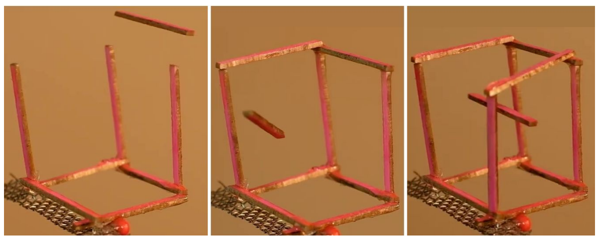

Figure 3. A cube built with sticks connected with UV-curable glue. The cube has 5 cm side, the sticks and the glue were levitated in a contactless way.

Electric sparks can be guided with ultrasound [27]. Electric sparks heat up the air, it expands and becomes less dense. This lower-density air gets shaped by the ultrasonic field due to the acoustic contrast in comparison with the surrounding ambient air. Also, less dense air has lower breakdown voltage and is a preferred discharge path. The process repeats and the ultrasonic field can guide the sparks along the high-amplitude areas. Being able to guide electric sparks enables new applications in high-voltage switching and selective welding. A guided electric spark is shown in Figure 4.

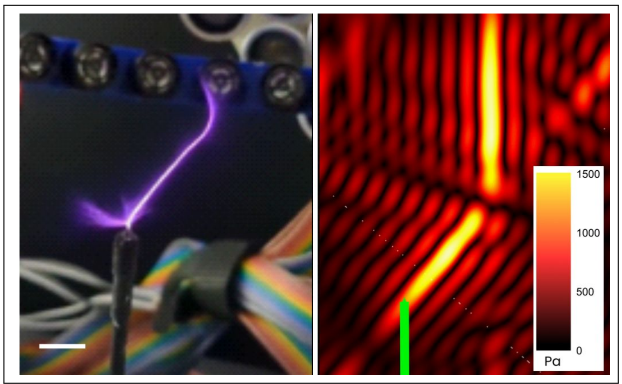

Figure 4. An electric spark is guided along the high-amplitude region of a 40 kHz ultrasonic field. left) guided spark. right) amplitude field. scale bar is 1 cm.

4. CONCLUSION

Acoustic levitation keeps evolving both in techniques and applications. Its low cost and larger scale of manipulation when compared with optical trapping makes acoustic levitation an active research topic.

5. ACKNOWLEDGMENTS

This research was funded by the European Research Consortium under grant agreement No 101042702 Intevol-ERC2021-STG.

6. REFERENCES

[1] E. Brandt, "Suspended by sound," *Nature*, vol. 413, no. 6855, pp. 474–475, 2001.

[2] R. Whymark, "Acoustic field positioning for containerless processing," *Ultrasonics*, vol. 13, no. 6, pp. 251–261, 1975.

[3] J. Weber, C. Rey, J. Neuefeind, and C. Benmore, "Acoustic levitator for structure measurements on low temperature liquid droplets," *Review of scientific instruments*, vol. 80, no. 8, 2009.

[4] D. Foresti, M. Nabavi, M. Klingauf, A. Ferrari, and D. Poulikakos, "Acoustophoretic contactless transport and handling of matter in air," *Proceedings of the National Academy of Sciences*, vol. 110, no. 31, pp. 12549–12554, 2013.

[5] A. Marzo and B. W. Drinkwater, "Holographic acoustic tweezers," *Proceedings of the National Academy of Sciences*, vol. 116, no. 1, pp. 84–89, 2019.

[6] D. Baresch, J.-L. Thomas, and R. Marchiano, "Observation of a single-beam gradient force acoustical trap for elastic particles: acoustical tweezers," *Physical review letters*, vol. 116, no. 2, p. 024301, 2016.

[7] A. Marzo, S. A. Seah, B. W. Drinkwater, D. R. Sahoo, B. Long, and S. Subramanian, "Holographic acoustic elements for manipulation of levitated objects," *Nature communications*, vol. 6, no. 1, p. 8661, 2015.

[8] A. Marzo, M. Caleap, and B. W. Drinkwater, "Acoustic virtual vortices with tunable orbital angular momentum for trapping of mie particles," *Physical review letters*, vol. 120, no. 4, p. 044301, 2018.

[9] S. Inoue, S. Mogami, T. Ichiyama, A. Noda, Y. Makino, and H. Shinoda, "Acoustical boundary hologram for macroscopic rigid-body levitation," *The Journal of the Acoustical Society of America*, vol. 145, no. 1, pp. 328–337, 2019.

[10] M. A. Andrade, N. Pérez, and J. C. Adamowski, "Review of progress in acoustic levitation," *Brazilian Journal of Physics*, vol. 48, pp. 190–213, 2018.

[11] M. A. Andrade, A. Marzo, and J. C. Adamowski, "Acoustic levitation in mid-air: Recent advances, challenges, and future perspectives," *Applied Physics Letters*, vol. 116, no. 25, 2020.

[12] A. Amoochi, M. Sheykholeslami Borghani, R. Mohammadi, and S. Mazdak, "Systematic review of the theories and applications of acoustic levitation of liquids," *Mechanic of Advanced and Smart Materials*, vol. 3, no. 3, pp. 310–324, 2023.

[13] R. J. Weber, C. J. Benmore, S. K. Tumber, A. N. Tailor, C. A. Rey, L. S. Taylor, and S. R. Byrn, "Acoustic levitation: recent developments and emerging opportunities in biomaterials research," *European Biophysics Journal*, vol. 41, pp. 397–403, 2012.

[14] S. Santesson and S. Nilsson, "Airborne chemistry: acoustic levitation in chemical analysis," *Analytical and bioanalytical chemistry*, vol. 378, pp. 1704–1709, 2004.

[15] H. Chen, Z. Hong, and D. Zang, "New insights into suspended drops: When soft matter meets acoustic levitation," *Droplet*, vol. 3, no. 1, p. e95, 2024.

[16] A. Marzo, A. Barnes, and B. W. Drinkwater, "Tinylev: A multi-emitter single-axis acoustic levitator," *Review of Scientific Instruments*, vol. 88, no. 8, 2017.

[17] S.-M. Argyri, C. Andersson, N. Paillet, L. Evenäs, J. Ahrens, A. Marzo, V. Contreras, and R. Bordes, "Customized and high-performing acoustic levitators for contact-free experiments," *Journal of Science: Advanced Materials and Devices*, vol. 9, no. 3, p. 100720, 2024.

[18] J. W. Drewitt, B. Emmens, Z.-H. Kong, B. W. Drinkwater, and A. C. Barnes, "Mightylev: An acoustic levitator for high-temperature containerless processing of medium-to high-density materials," *Review of Scientific Instruments*, vol. 95, no. 10, 2024.

[19] R. Morales, I. Ezcurdia, J. Irisarri, M. A. Andrade, and A. Marzo, "Generating airborne ultrasonic amplitude patterns using an open hardware phased array," *Applied Sciences*, vol. 11, no. 7, p. 2981, 2021.

[20] I. Ezcurdia, R. Morales, M. A. Andrade, and A. Marzo, "Leviprint: Contactless fabrication using full acoustic trapping of elongated parts.," in *ACM SIGGRAPH 2022 Conference Proceedings*, pp. 1–9, 2022.

[21] M. A. Andrade, T. S. Camargo, and A. Marzo, "Automatic contactless injection, transportation, merging, and ejection of droplets with a multifocal point acoustic levitator," *Review of Scientific Instruments*, vol. 89, no. 12, 2018.

[22] Y. Koroyasu, T.-V. Nguyen, S. Sasaguri, A. Marzo, I. Ezcurdia, Y. Nagata, T. Yamamoto, N. Nomura, T. Hoshi, Y. Ochiai, *et al.*, "Microfluidic platform using focused ultrasound passing through hydrophobic meshes with jump availability," *PNAS nexus*, vol. 2, no. 7, p. pgad207, 2023.

[23] A. Marzo, T. Corkett, and B. W. Drinkwater, "Ultraino: An open phased-array system for narrowband airborne ultrasound transmission," *IEEE transactions on ultrasonics, ferroelectrics, and frequency control*, vol. 65, no. 1, pp. 102–111, 2017.

[24] R. Montano-Murillo, R. Hirayama, and D. Martinez Plasencia, "Openmpd: A low-level presentation engine for multimodal particle-based displays," *ACM Transactions on Graphics*, vol. 42, no. 2, pp. 1–13, 2023.

[25] S. Zehnter and C. Ament, "A modular fpga-based phased array system for ultrasonic levitation with matlab," in *2019 IEEE International Ultrasonics Symposium (IUS)*, pp. 654–658, IEEE, 2019.

[26] J. M. 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.

[27] J. Irisarri, I. Ezcurdia, N. Iriarte, M. Sirkka, D. Nikolaev, J. Mäkinen, A. Martinez-Marchese, D. Iablonskyi, A. Salmi, and A. Marzo, "Electric plasma guided with ultrasonic fields," *Science Advances*, vol. 11, no. 6, p. eadp0686, 2025.