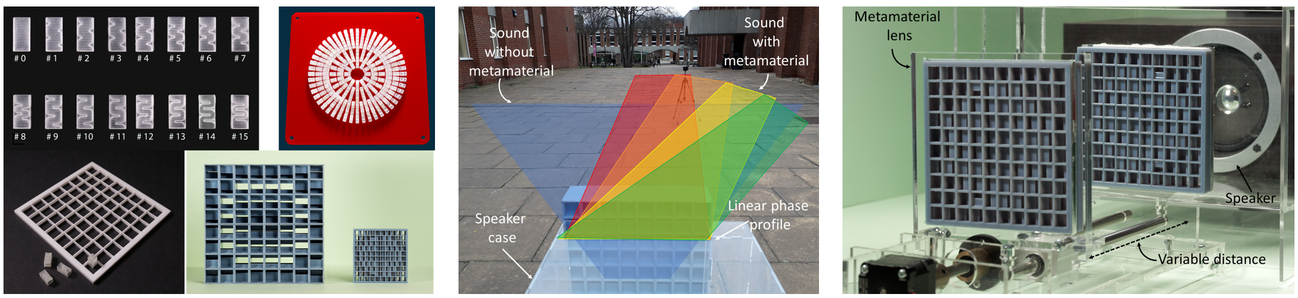
From Light To Sound: Prisms And Auto-Zoom Lenses

Gianluca Memoli
Thomas J. Graham
g.memoli@sussex.ac.uk
t.j.graham@sussex.ac.uk
University of Sussex (UK)

Joshua T. Kybett
Arash Pouryazdan
JKybett@JKybett.uk
ap293@sussex.ac.uk
University of Sussex (UK)



(a) (b) (c)

Figure 1: We use 3D-printed metamaterial bricks in different assemblies (a) to realise acoustic systems similar to their optical counterparts: an acoustic prism (b), and an auto-zoom objective (c), designed to deliver sound to a tracked target.

ABSTRACT

In this talk, we show how acoustic metamaterials can be used to build the acoustic equivalent of optical devices. We demonstrate two key devices: (1) an acoustic prism, used to send the different notes in a melody towards different directions, and (2) an auto-zoom lens, used to send sound to a moving target. We conclude, discussing potential applications and limitations.

CCS CONCEPTS

• **Human-centered computing** → **Sound-based input / output**; • **Hardware** → *Emerging technologies.*

KEYWORDS

Microstructures, Fabrication, Localised Audio, 3D Printing.

ACM Reference Format:

Gianluca Memoli, Thomas J. Graham, Joshua T. Kybett, and Arash Pouryazdan. 2019. From Light To Sound: Prisms And Auto-Zoom Lenses. In *Proceedings of SIGGRAPH '19 Talks.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3306307.3328206

1 INTRODUCTION

For many years, applications ranging from sonars to home-theatres and virtual reality (VR) have achieved acoustic beam-forming through arrays of digital controlled speakers, which can be considered equivalent to a LCD display for light. Light designers, however, can also count on simpler passive devices, like lenses and filters, which are usually inserted between sources and receivers and are more frequently used. Until a few years ago, acoustic lenses and filters were bulky and easily broken. Recent advances in computational modelling and additive manufacturing, however, have sparked a new age for material design. Classical materials, like wood or glass or plastic, can now be micro-engineered to create functional devices [Ion et al. 2017] and optical displays [Ochiai et al. 2018]. "Metamaterials", as this technology is named, open to low-cost solutions that, until a few years ago, were not possible for sound. In acoustics, metamaterials with sub-wavelength thickness (also known as "metasurfaces") have successfully achieved with sound optical effects like anomalous refraction [Tang et al. 2014] and self-bending beams [Zhu et al. 2016]. Memoli et al. [2017] showed that metasurfaces may be assembled using modular, digital designs based on pre-fabricated "lego-like" bricks. The thickness of these bricks, however, is still too large for their practical use in HCI, unless used at ultrasound frequencies [Jackowski-Ashley et al. [n. d.]]. Also, metasurfaces are static: once the shape of the field is set, it cannot be changed, unless a hybrid system is used [Norasikin et al. 2018]).

In this talk, we show how acoustic metasurfaces of HCI-friendly dimensions can be used to give a user-controlled spatial characteristic to the sound coming from a standard commercial audio speaker. We demonstrate two key devices: (1) an acoustic prism and (2) and auto-zoom lens. Like an optical prism can be used to split white light, so that different colors go in different places, our acoustic prism sends different notes in a melody into different positions. Similarly, our auto-zoom lens uses face-tracking algorithms to send sound to a moving person, at different distances from the speaker.

SIGGRAPH '19 Talks, July 28 - August 01, 2019, Los Angeles, CA, USA

ACM ISBN 978-1-4503-6317-4/19/07.
https://doi.org/10.1145/3306307.3328206

2 METAMATERIAL BRICKS

Memoli et al. [2017] showed how metasurfaces can be assembled using just 16 types of pre-printed metamaterial bricks, each encoding a delay to the sound propagating through. One possibility is to design these bricks as a labyrinthine meander, optimised to maximise the transmitted sound [Memoli et al. 2017]. A further optimisation, run on the "thickness" of the bricks, leads to different designs (see Figure 1a), each operating over different bandwidths [Memoli et al. 2019]. In this talk, we show how to use libraries of different brick designs to construct a range of passive devices.

3 ACOUSTIC PRISM

Optical prisms [Born and Wolf 1970] are transparent to light and are structured to "split" white light into individual frequencies i.e. obtaining a rainbow. In our realisation for acoustics (Figure 1b), we exploit anomalous refraction, and in particular the dependence of the exit angle θ on the wavelength λ, in presence of a phase gradient along the metasurface [Yu et al. 2011], like the one created by bricks of different design. As shown in Figure 2, in this way it is possible to spatially separate the different notes from the chromatic scale

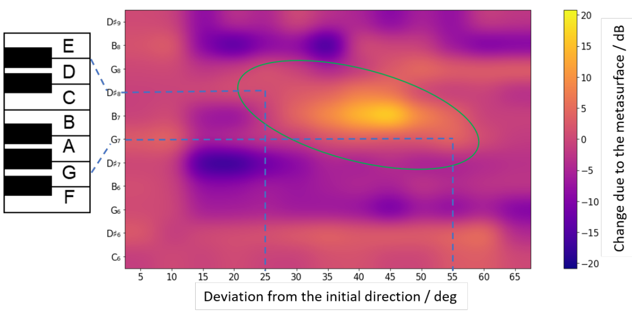
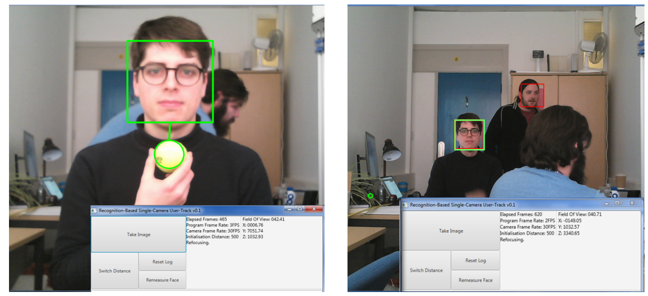


Figure 2: Acoustic prism at work: the chromatic notes between G and D (in this case, within the 7th octave), get deviated at angles between 25° and 55°, depending on their wavelength. The presence of areas of lower intensity confirm that the sound is confined within a limited, rainbow-like beam.

4 ACOUSTIC AUTO-ZOOM OBJECTIVE

A system of lenses can image objects at a distance (telescopically). In reverse, it can be used to send light to a receiver. Automated, it leads to the auto-zoom objectives in cameras and early VR headsets.

Using an array of metamaterial bricks, it is possible to assemble a convex (convergent) lens for sound [Li et al. 2014; Memoli et al. 2017; Tang et al. 2014] i.e. a magnifying glass, characterised by its focal length f. Mounting two converging lenses, with different focal lengths f_1, f_2, at a relative distance d is the simplest way of realising an acoustic vari-focal lens (i.e. a telescope). With a similar set-up, it is possible to focus sound on a selected target, positioned at a distance s, by adjusting the distance d as we typically do with a manual-focus objective. In this talk, we show how an in-house face-tracking software (see Figure 3) can be used to pilot an Arduino-controlled telescope, thus focusing sound on a moving target, towards personalised audio communication



(a) (b)

Figure 3: Our acoustic auto-zoom at work: a face is selected using a reference object (a) and then tracked in subsequent frames to obtain the distance d (b). Open CV was used for face recognition and camera control, JSerial for interacting with an Arduino motorised telescope.

5 LIMITATIONS AND FUTURE WORK

The key limitations of acoustic metamaterials is their bandwidth. In Figure 2, for instance, we used bricks that respond to notes from G to D in octaves 3 and 7, but not elsewhere. Similar devices are sufficient for alarms and acoustic cues, but cannot convey the 11 octaves that form our audible range. Bandwidth, however, is a design parameter like the spatial footprint: our autozoom objective incorporates lenses operating over a whole octave, and thus sufficient to focus a basic melody. Future studies will look at ways to increase the bandwidth, both at the single brick and at the device level (e.g. cascading lenses/filters operating at different frequencies).

ACKNOWLEDGMENTS

The work was funded by the UK Engineering and Physical Sciences Research Council (EPSRC-UKRI) through grant EP/S001832/1.

REFERENCES

K. Born and W. Wolf. 1970. *Principles of Optics.* Pergamon Press.

A. Ion, L. Wall, R. Kovacs, and P. Baudisch. 2017. Digital Mechanical Metamaterials. In *Proceedings of ACM CHI '17 (CHI '17).* ACM, New York, NY, USA, 977–988.

L. Jackowski-Ashley, G. Memoli, M. Caleap, N. Slack, B.W. Drinkwater, and S. Subramanian. [n. d.]. Haptics and Directional Audio Using Acoustic Metasurfaces.

Y. Li, X. Jiang, R. Li, B. Liang, X. Zou, L. Yin, and J. Cheng. 2014. Experimental Realization of Full Control of Reflected Waves with Subwavelength Acoustic Metasurfaces. *Phys. Rev. Applied* 2 (Dec 2014), 064002. Issue 6.

G. Memoli, M. Caleap, M. Asakawa, D.R. Sahoo, B.W. Drinkwater, and S. Subramanian. 2017. Metamaterial bricks and quantization of meta-surfaces. *Nat. Comms.* 8 (2017).

G. Memoli, L. Chisari, J.P. Eccles, M. Caleap, B.W. Drinkwater, and S. Subramanian. 2019. VARI-SOUND: A Varifocal Lens for Sound. In *Proceedings of ACM CHI '19 (CHI '19).* ACM, New York, NY, USA, Article 483, 14 pages.

M.A. Norasikin, D. Martinez Plasencia, S. Polychronopoulos, G. Memoli, Y. Tokuda, and S. Subramanian. 2018. SoundBender: Dynamic Acoustic Control Behind Obstacles. In *Proceedings of the ACM UIST '18 (UIST '18).* 247–259.

Y. Ochiai, K. Otao, Y. Itoh, S. Imai, K. Takazawa, H. Osone, A. Mori, and I. Suzuki. 2018. Make Your Own Retinal Projector: Retinal Near-eye Displays via Metamaterials. In *ACM SIGGRAPH 2018 Posters (SIGGRAPH '18).* Article 48, 2 pages.

K. Tang, C. Qiu, M. Ke, J. Lu, Y. Ye, and Z. Liu. 2014. Anomalous refraction of airborne sound through ultrathin metasurfaces. *Scientific Reports* 4 (2014).

N. Yu, P. Genevet, M.A. Kats, F. Aieta, J.-P. Tetienne, F. Capasso, and Z. Gaburro. 2011. Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction. 334 (2011), 333–337.

X. Zhu, K. Li, P. Zhang, J. Zhu, J. Zhang, Chao T., and S. Liu. 2016. Implementation of dispersion-free slow acoustic wave propagation and phase engineering with helical-structured metamaterials. *Nature Communications* 7 (2016).