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Focusing Ultrasonic Vortices across the Human Skull by Acoustic Holograms

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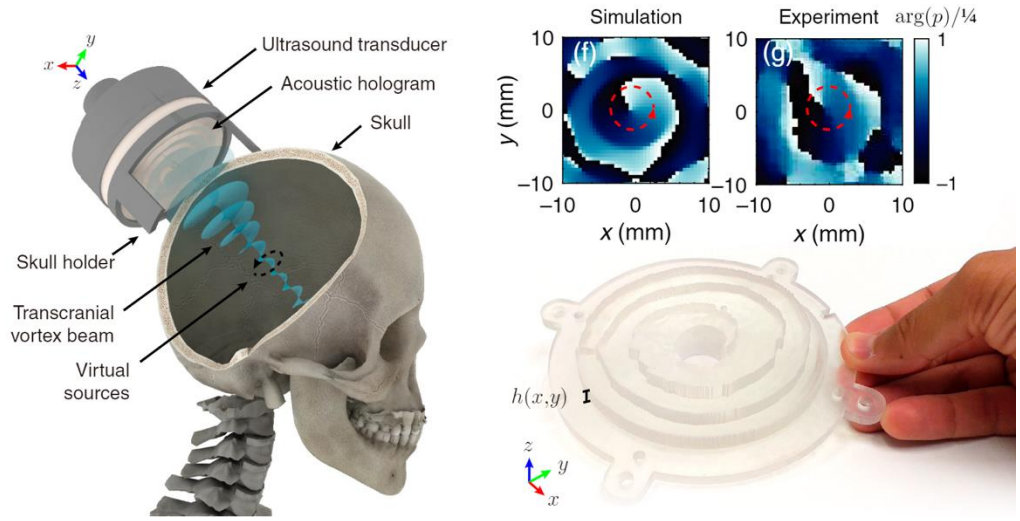
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Acoustic vortices can be applied to trap and guide drug delivery carriers, microbubbles, or small objects. However, focusing acoustic waves through aberration layers such as the skull at ultrasonic frequencies results in strong phase aberrations, preventing the generation of sharp acoustic vortices. In this work, we demonstrate that phase-conjugated acoustic holograms can encode time-reversed fields simultaneously allowing the compensation of the aberrations of the skull and the generation of a focused vortex inside an ex-vivo human skull.

An acoustic hologram is designed by time-reversal methods using CT images of an ex-vivo human skull. The lens is 3D printed using stereolithographic techniques, coupled to a 100-mm aperture, 140-mm focal and 500-kHz focused ultrasound transducer. The field is measured with and without the skull bone in a water tank.

Measurements agree with simulations in both, water and including the skull. The acoustic hologram generates a focused vortex at an arbitrary focal position inside the skull by encode time-reversed fields containing phase dislocations with great accuracy using very simple and compact ultrasonic systems. Acoustic holograms allow to compensate the aberrations of the skull, and, simultaneoulsy, they tune the phase of the wavefront to generate a focused vortex by introducing a rotational phase profile. This results in a personalized single-element system to focus a vortex inside the human brain.

This work paves the way for low-cost particle-trapping systems, clot manipulation, torque exertion, and acoustic-radiation-force-based biomedical applications in the brain, opening a path to exploring the biological response of tissues to therapeutic ultrasonic vortex beams.



Scheme of the concept, photograph of the hologram and phase of the field in the transverse direction inside the skull.