CONFORMATION OF ULTRASONIC VORTEX BEAMS THROUGH THE SKULL FOR PARTICLE TRAPPING USING ACOUSTIC HOLOGRAMS

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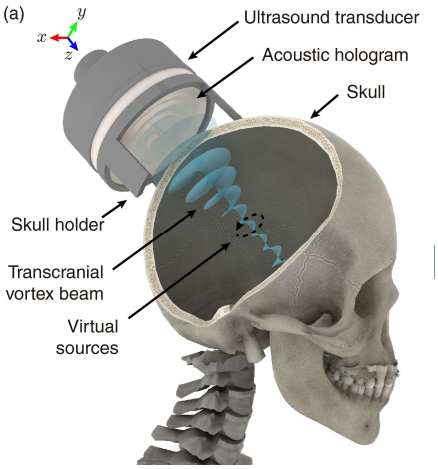
INTRODUCTION

Background

Acoustic tweezers are a versatile and powerful emerging tool to biomedical applications, such as cell manipulation or drug delivery, as they allow contactless particle manipulation using low-power devices. Single beam acoustic tweezers based on vortex beam require a focused ultrasound beam containing a phase dislocation at its axis. While these beams have demonstrated great potential to trap particles in homogeneous media, phase aberrations produced by strongly heterogeneous and refracting media distorts the wavefront and inhibit the generation of trapping forces.

Our proposal

In this work we report a method to conform aberration-free focused vortex beams through the skull for transcraneal particle trapping using acoustic holograms



Simulations

When the skull in present, pseudo-spectral (*k*-space) and time-domain simulations of the constitutive relations for acoustic waves in heterogenous media including frequency-power law absorption and dispersion is used:

$$\frac{\partial \rho}{\partial t} = -\rho_0 \nabla \cdot \mathbf{u} - \mathbf{u} \cdot \nabla \rho_0,$$
$$\frac{\partial \mathbf{u}}{\partial t} = -\frac{1}{\rho_0} \nabla p,$$
$$p = c_0^2 \left(\rho + \mathbf{d} \cdot \nabla \rho_0 - \mathrm{L}\rho\right),$$

Experiments

Calculations are validated with measurements in a water tank at 500 kHz using a transducer of 90-mm aperture and 110-mm focal transducer and an exvivo human skull.

HOLOGRAM DESIGN

(1) Image acquisition

CT images provide bone apparent density used for simulation methods.



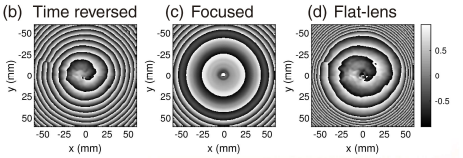
MRI tomographic data segmentation of the soft-tissues under interest is required for treatment planning.

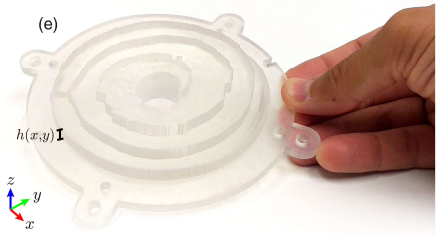
(2) Back-propagation

Time-reversal: a focused field containing a phase dislocation is numerically backpropagated from the target CNS structure to the lens surface. A diffraction-limited version of the wavefront is captured.

(3) Lens construction

Only-phase plates: The holographic information is used to calculate the lens geometry [1]. We assume each pixel of the lens vibrates as a Fabry-Pérot resonator.



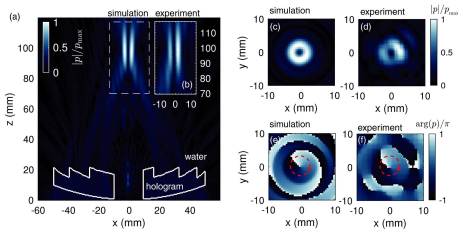


3D-printing: lenses are manufactured using SLA 3D printing and photo-sensitive polymers.

RESULTS

a) Calibration in water

The field was scanned using a hydrophone and a steeped 3D axis. Signals were acquired and post processed using the FFT to extract the magnitude and phase of the field at 500 kHz. Simulated and experimental field cross-sections were compared, and the maps obtained by both methods agreed.

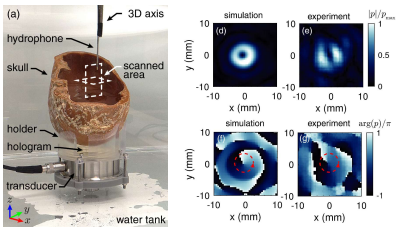


A focused vortex with a topological charge of 1 was detected, in agreement with the design.

RESULTS (Cont.)

b) Transcranial vortex focusing

Hydrophone measurements inside the skull immersed in a water bath indicate that an aberration-free vortex is generated.



c) Particle trapping

The system allows to trap small particles (500 μm, elastic polymer) in a water bath.

The trapping is stable for both, continuous wave and pulse-burst excitation (10 Hz PRF). Heating of the lens was moderate, below 40 °C at the surface. Due to electrical impedance mismatch, no trapping was performed through the skull.



CONCLUSIONS

Summary

Using holographic lenses, acoustic vortices were experimentally and numerically synthesized inside an ex-vivo human skull.

Conclusion

Holographic lenses enable the generation of aberration-free vortices inside the human head using a low-cost and robust system.

Impact

This low-cost and simple approach opens the path to trap and manipulate small particles and objects inside the head. The method could be used to trap and guide therapeutical vehicles such as microbubble clusters or clots. In addition, orbital angular momentum can be transferred to brain tissue, enabling possible applications in therapeutic ultrasound applications including neuromodulation.

A **patent** of invention has been approved.

Next steps

ex-vivo experiments for particle trapping.
in-vivo experiments using holograms and small laboratory animals.

REFERENCES

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Single element transducers | Phased-arrays systems | 3D Printed Lenses | Tailored Holograms | Reconfigurable metasurfaces