ULTRASOUND HOLOGRAMS TO ENHANCE DEEP-BRAIN NEUROMODULATION

Diana Andrés, Sergio Jiménez-Gambín, Noé Jiménez, Francisco Camarena, José María Benlloch

Instituto de Instrumentación para Imagen Molecular, CSIC- Universitat Politècnica de València, 46022 València, Spain

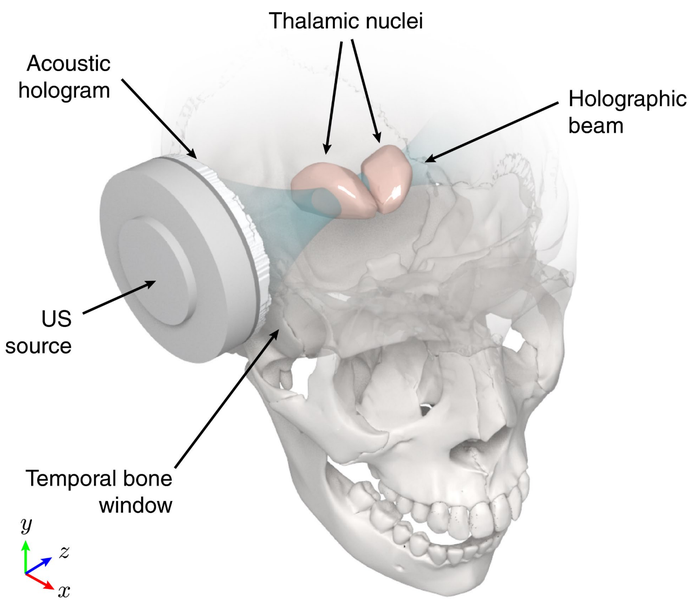
INTRODUCTION

Background

Transcranial focused ultrasound is widely used for neuromodulation at moderate intensity. To achieve a good treatment, it is important to have a control of the transducer focus location relative to the target of interest, but when ultrasound propagates through the skull it suffers from aberrant and attenuating effects that result in an undesired defocusing and uncertainty of the focus shape and location. Moreover, some nuclei of interest for neuromodulation are symmetrical in both brain hemispheres and current technologies are not capable of a simultaneous sonication of this structures.

Our proposal

In this work we present the capability of acoustic holograms to control the focus shape and location even through the skull. Holograms can adapt ultrasound fields to deep-brain targets of interest for neuromodulation, such as hippocampus or thalamic nuclei.



METHODS

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:

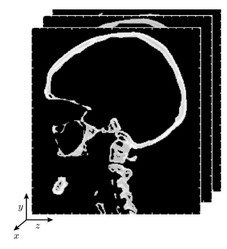
$$\frac{\partial \rho}{\partial t} = -\rho_0 \nabla \cdot \mathbf{u} - \mathbf{u} \cdot \nabla \rho_0,$$
$$\frac{\partial \mathbf{u}}{\partial t} = -\frac{1}{\rho_0} \nabla p,$$
$$p = c_0^2 \left(\rho + \mathbf{d} \cdot \nabla \rho_0 - \mathrm{L}\rho\right),$$

Experiments

Calculations are validated with measurements in a water tank at 500 kHz using a transducer of 90 mm of aperture and 140 mm focal length, and an ex-vivo human skull

HOLOGRAM DESIGN

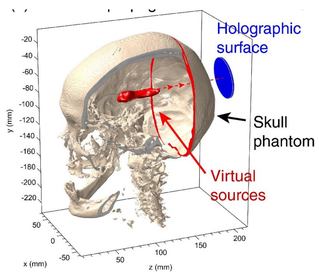
(1) Image acquisition



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.

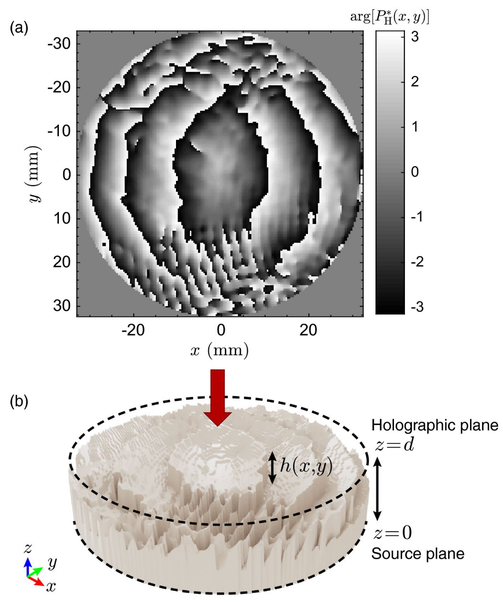
(2) Back-propagation



Time-reversal: the field 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.

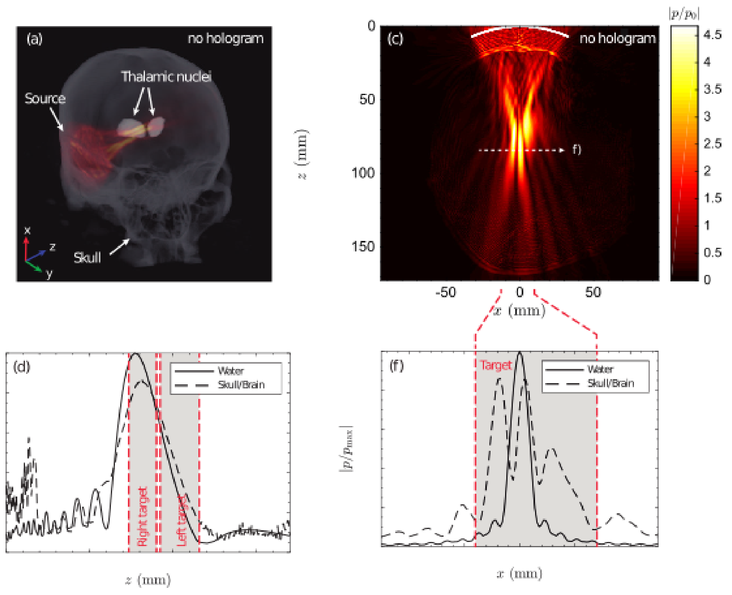


3D-printing: lenses are manufactured using a SLA printer and photo-sensitive polymers.

RESULTS

a) Focused transducer

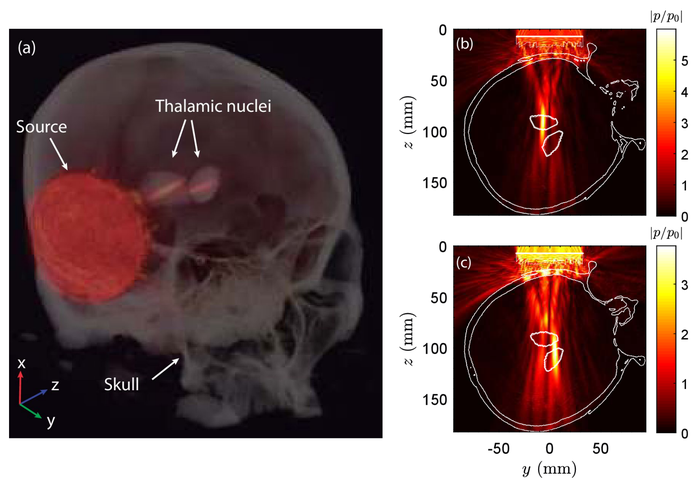
First, we show how a standard focused transducer can be focused to the thalamic nuclei. Using this approach, the focus can be aberrated and the energy is not efficiently focused at the target. The bilateral structure cannot be covered totally by the therapeutic beam.



RESULTS (cont.)

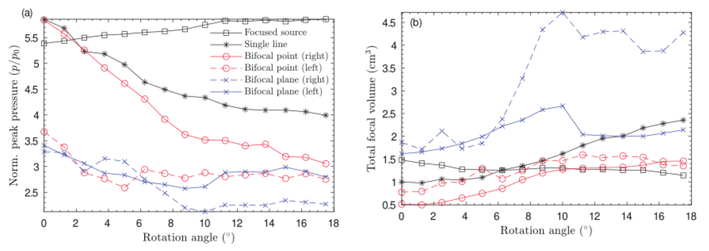
b) Bilateral focusing using holograms

Results show that more than 20 % of the volume of bilateral targets inside the brain can be covered with a single hologram while minimizing the sonicated non-objective brain tissue.



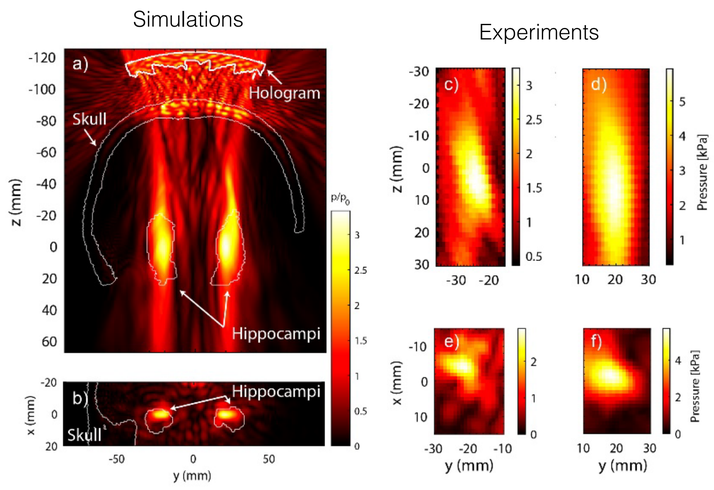
c) Robustness against misalignments

Simulations show that holograms maintain their focusing performance under misalignments up to 5 degrees of rotation and 2 m of translation. This paves the way to implement this technique using optical neuronavigation systems .



d) Experimental validation

Acoustic beams are simultaneously targeted at both hippocampi for experimental validation. Using holograms, energy is focused on target locations. Simulations and experiments agree in water with sub-millimetric accuracy.



CONCLUSIONS

Conclusion

Acoustic holograms are a robust and low-cost system to focus ultrasound beam through the skull into deep-brain nuclei for precise and selective neuromodulation applications.

REFERENCES

[1] S Jiménez-Gambín, et al. Holograms to focus arbitrary ultrasonic fields through the skull. Physical Review Applied, 12 (1), pp. 014016, (2019)

[2] D. Gabor, Nature 161, 777 (1948).

[3] G Maimbourg, at al. Phys Med & Biolog 63, 025026 (2018).

[4] JL Thomas and M Fink, IEEE Trans Ultrason Ferroelectr Freq Control 43, 1122 (1996).

[5] J Sun and K Hynynen, J Soc Ac Am 104, 1705 (1998).

Instituto de Instrumentación para Imagen Molecular

CSIC Consejo Superior de Investigaciones Científicas

Generalitat Valenciana | Tots a una veu

AVI Agència Valenciana de la Innovació

Single element transducers → Phased-arrays systems → 3D Printed Lenses → Volumetric Holograms → Reconfigurable metasurfaces