Thermal patterns generated by acoustic holographic lenses

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In this work we numerically and experimentally demonstrate how 3D-printed acoustic holograms can generate thermal holographic patterns in absorbing media, such as soft-tissues. By encoding the acoustic wavefront information in artificially structured media, holograms can concentrate the acoustic energy in arbitrary regions to create sharp images. Then, absorption is activated mainly at the desired target spots and, therefore, temperature rises following the shape of the acoustic images. Two thermal patterns were created: one with the shape of the number '2', designed for a flat transducer of aperture 2a = 50 mm operating at 1.1 MHz, and other designed to enlarge the natural focus of an elliptical focused transducer with 2a = 125 mm major axis, 2b = 85 mm minor axis and R = 100 mm radius of curvature, working at 1 MHz.

Acoustic holograms were designed with a time-reversal method, described by Jiménez-Gambín et al (1). The back-propagated acoustic field is recorded in a parallel surface to the transducer and the phase information at the transducer central frequency is retained and complex-conjugated. The corresponding holographic lens is designed tuning each pixel heigh assuming it vibrates as a Fabry-Perot resonator. Acoustic and thermal diffusion simulations considering the resulting lens were performed using a *k*-space pseudo-spectral method implemented in the software k-Wave (2), which considers absorption. Experiments were carried out to characterize acoustic fields in degassed water with a hydrophone and thermal holographic patterns in liver tissue and soft-tissue phantoms with an infrared (IR) camera and MR-thermometry.

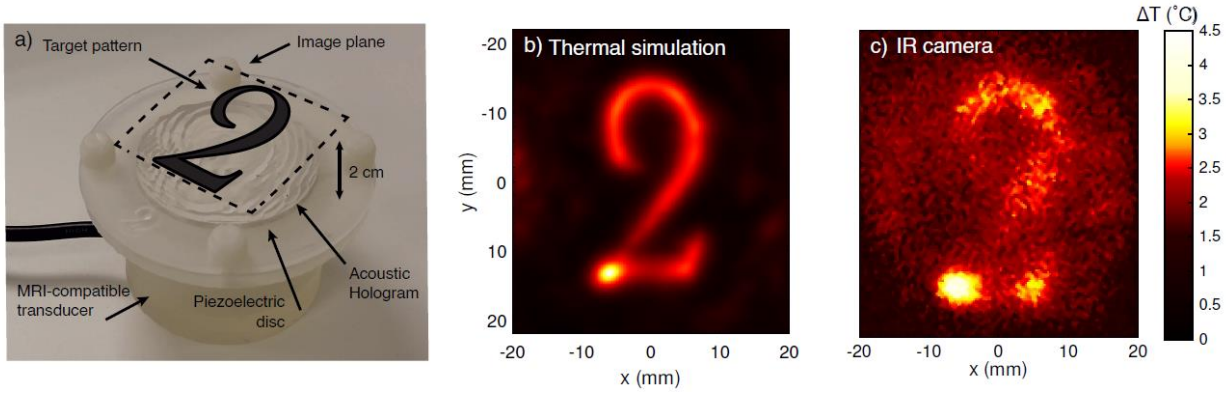


Figure 2. a) 3D-printed MRI-compatible transducer and holographic lens. b) Simulated thermal pattern in liver tissue after 12 s heating. c) Thermal pattern measured with an infrared camera in liver tissue after 12 s heating.

Acoustic simulations and experimental measurements of the number "2" hologram were in good agreement, with a relative error of 31%. Thermal holographic patterns measured with both MR-thermometry and IR-camera matched with thermal simulations. For the '2' hologram, peak temperature raised 4.5° C after 12 s of heating at 20 W acoustic power. A second hologram was designed to enlarge the focal spot of a focused transducer. For this hologram, regions inside which simulated temperature elevation was greater than 4° C were 17 × 16 mm^2 and 7 × 25 mm^2 without and with the lens respectively, while these same experimental measurements resulted in region sizes of 11 × 16 mm^2 and 7 × 30 mm^2. Standard deviation inside these regions was equal to 40% of the maximum temperature without the holographic lens and 12% using it. Temperature at the focal spot raised 6° C after 30 seconds heating, as required to perform a hyperthermia treatment.

In conclusion, thermal holographic patterns can be created in absorbing media, as soft tissue, using 3D-printed holographic lenses. Heating region can be well controlled and adapted to any therapeutical target regardless of its shape and location. A mild temperature rise in a localized area is of great interest for biomedical applications such as ultrasound hyperthermia, physical therapy, or thermal drug delivery, between others. This technology can be used coupled to low-cost MR-compatible transducers as an alternative to phased-array systems used in clinics for therapeutical treatments.

References

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