Thermal patterns generated by ultrasound holograms

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In this work, we use 3D-printed acoustic holographic lenses coupled to a low-cost magnetic resonance imaging (MRI) compatible transducer to create thermal holographic patterns in an absorbing medium. First, acoustic holograms are designed with time-reversal methods, considering the time invariance of the acoustic wave equation, by setting virtual sources along the shape of the desired acoustic image. The wavefront produced by these point sources is numerically computed and captured in a plane parallel to the transducer surface. The corresponding holographic lens is designed with the complex conjugated phase information of the wavefront at the transducer working frequency, considering each column of the lens vibrates as an elastic Fabry-Pérot resonator [1]. To evaluate the acoustic field generated in the medium, numerical simulations were performed with a k-space pseudo-spectral method [2]. With the maximum pressure of the resulting field in stationary state we calculate the tissue heating by solving the Penne's bio-heat equation [3], retrieving the desired holographic thermal pattern.

Two thermal patterns were designed: one with the shape of the number '2' designed for a flat transducer and other designed to enlarge the natural focus of an elliptical focused transducer for therapeutical applications. To characterize the holographic acoustic field generated by the transducer-lens system, measurements were done with a piezoelectric hydrophone in degassed water. Thermal pattern was experimentally generated in liver tissue and measured with two different instrumentals: and infrared (IR) camera recording the temperature field at the surface of the tissue and MR-thermometry.

Simulation and measurement of the '2'-shaped acoustic-hologram are in good agreement, with a relative error of 31%. Thermal holographic patterns measured with IR-camera and MR-thermometry matched with thermal simulations (Figs. 1b and 1c). For this image, peak temperature raised 4.5 °C after 12 s at 20 W acoustic power. For the focused transducer hologram, an ellipsoidal thermal pattern of 7 × 30 mm^2 size was obtained, modifying its natural focus of 11 × 16 mm^2, and raising the focal spot temperature up to 6 °C after 30 s.

In conclusion, with the use of 3D-printed holographic lenses, thermal holographic patterns can be generated in absorbing media. With acoustic holograms, heating region can be adapted to very specific therapeutical targets in any part of the body. This technology is proposed as a low-cost alternative to phased-array systems used in clinical applications for hyperthermia treatments.

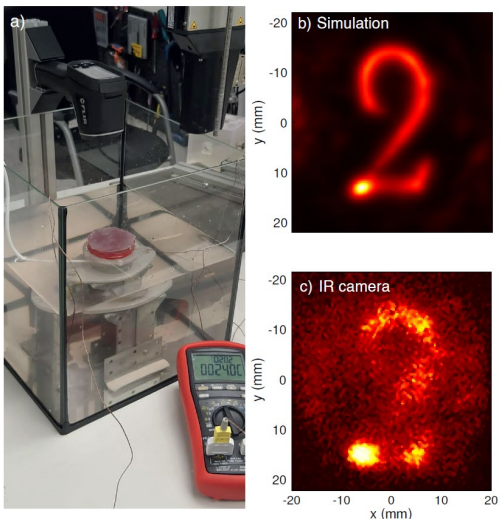


Figure 1. a) Experimental setup. b) Simulated and c) experimental thermal pattern.

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