Magnetic Resonance Imaging of Continuous ultrasound holograms

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Introduction

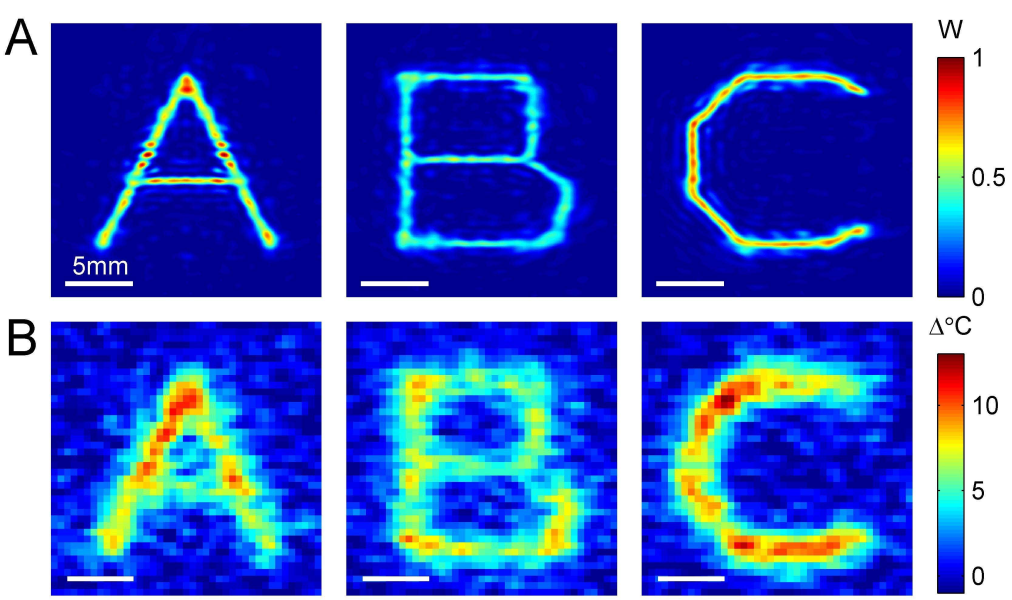
The growing clinical activity and applications of magnetic resonance guided focused ultrasound (MRgFUS), e.g. hyperthermia and ultrasound neural stimulation, and the increasing number of high intensity ultrasound phased arrays' transmitting elements, call for the development of ultrasound holograms algorithms to induce complex spatial distributions of acoustic intensities. Previous study of ultrasound multifocal patterns [1] shows that multiple focal points can be generated efficiently, uniformly and simultaneously using computer generated holograms algorithms adapted from the optics research field. Here we report, for the first time, on a uniform and accurate continuous ultrasound patterns using the weighted Gerchberg-Saxton (GSW) algorithm and FFT based acoustic field calculations using backward and forward planar projections [2].

Material and Methods

Continuous two-dimensional ultrasound holograms were generated using the iterative GSW algorithm. Each one of the iterations begins with forward projection of the planar transducer acoustic field to the target plane using FFT based calculation. The target acoustic field amplitude is than modified according to requested hologram intensities. The iteration ends by backward projection of the acoustic field from the target plane to the transducer plane, from which the transducer elements' phases are sampled. Following the GSW algorithm weightings, the requested hologram intensities were modified each iteration according to the target relative intensity ($W_{m,t}=W_{m,t-1}\bullet\langle p_{t-1}\rangle\bullet|p_{m,t-1}|^{-1}$, where $W_{m,t}$ and $p_{m,t}$ are the relative and simulated acoustic field amplitudes of the mth pixel in iteration t). Simulations were performed using 2048x2048 pixels matrixes of complex numbers to span an acoustic field plane of 10.2x10.2cm using 50x50µm resolution. The three letters patterns, 'A', 'B' and 'C', were manually built into 1.5x1.5cm masks to represent the requested target fields at a parallel plane, 25mm from the transducer plane. The initial conditions were chosen to be random phases for transducer acoustic field and the targets' weights were set to one ($W_{m,0}$= 1).

MRI temperature elevation images were acquired on a GE 1.5T scanner equipped with Insightec FUS transducer (FSPGR sequence, TR/TE=35.8/22.8ms, FOV=12.8x12.8cm, slice thickness=5mm, in plane resolution of 0.5x0.5mm). A reference scan that was taken before sonication was subtracted from a scan taken 5 seconds after beginning of sonication to measure the temperature elevation.

Sonication of 49.4W acoustic power and 10sec duration was performed to a focal plane 25mm from Insightec ultrasound phased array transducer, which was originally designed for the treatment of prostate tumors.



Results

Two-dimensional ultrasound holograms of the first three English letters were generated on a relatively small area of 1.5x1.5cm (Fig. 1). The GSW algorithm was converged after eight iterations of forward and backward projections.

Figure 1. (A) Acoustic field normalized power simulations generated using two-dimensional GSW algorithm and FFT based backward and forward planar projections.
(B) MRI temperature elevation measurements induced by FUS into a focal plane of 25mm from transducer plane using the computer generated acoustic phase maps.

Discussion and Conclusions

We have demonstrated that continuous two-dimensional ultrasound holograms can be generated accurately and efficiently using ultrasound phased array transducer. Ultrasound holograms may be useful for FUS applications, such as tissue ablation and ultrasound neural stimulation in two aspects: time-efficiency and the improvement of temporal and spatial acoustic field distributions. Increasing the time-efficiency of FUS treatment, which is important especially for tissue ablation, is feasible by heating simultaneously and uniformly a large shaped target rather than a single point at a time. In addition, improvement of acoustic field temporal and spatial distributions using ultrasound holograms can be used to stimulate complex neural structures simultaneously and for improvement of FUS treatments safety using shaped acoustic field spatial distributions, e.g. reduce energy on ribs bone for the hyperthermia treatment of the liver.

References (1) Hertzberg Y. et al. J. Nerural Eng. 2010;7:056002. (2) G. T. Clement et al. J. Acoust. Soc. Am. 2000;108(1):441-6.