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67 TWO-DIMENSIONAL ARRAY SYNTHESIS USING RASTER-SCANNED SINGLE HYDROPHONE IN APPLICATION TO ACOUSTIC HOLOGRAPHY AND ULTRASOUND IMAGING

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OBJECTIVES

Two-dimensional (2D) receiving arrays with ~10^4 total number of elements would serve as a powerful tool for ultrasound imaging, especially in the situations when the region of interest is imaged through inhomogeneous layers like skull or ribs. While 2D arrays with such a large number of elements are not yet practically available, their imaging capabilities can be studied by replacing them with synthetic 2D receiving arrays that are made using a single hydrophone that is raster scanned by a computer-controlled positioner. The goal of this study is to illustrate such an approach experimentally by using a synthetic 2D array in two applications: acoustic holography of therapeutic ultrasound sources and ultrasound imaging through a skull phantom.

METHODS

To create a synthetic array, a miniature ultrasound probe was moved point-to-point using a computer-controlled positioning system. Measurements were made in degassed water using several experimental arrangements, in which the ultrasound probes were either capsule or needle hydrophones with sensitive diameters of 0.15, 0.2, or 0.5 mm. The scans were executed using positioning systems with stepper motors and linear slides that provided a resolution of several microns per step. In each scan, the hydrophone was sequentially located at the nodes of a square grid with a pitch less than half the wavelength. Typical size of the scanning region was 100×100 points, which corresponded to the number of elements of the corresponding virtual synthetic array. At each hydrophone position, an ultrasound source emitted a tone burst which was received by the hydrophone. Then, a hydrophone was moved to a new location and the operation of emission-reception was repeated. The pressure waveform at each location was recorded using a digital oscilloscope and transferred to a computer.

RESULTS

Synthetic arrays were used for two applications: The first was acoustic holography, which was shown in our previous work to be a powerful technique for characterizing ultrasound sources and the fields they radiate [see 1,2]. Beyond the CW version of holography that is appropriate for most regimes of ultrasound therapy, transient holography is directly relevant to imaging applications and therapies like histotripsy [3]. Here, a transient hologram was detected by a synthetic array (150×150 size, 0.7 mm pitch) in order to characterize a piezoelectric HIFU source (10 cm diameter, 10 cm focal length) excited by a 7-cycle tone burst at a frequency of 1 MHz. The reconstructed vibration velocity magnitude is shown in Figure. 1.

The second application of synthetic arrays was ultrasound pulse-echo imaging through an inhomogeneous layer mimicking a human skull. Transcranial ultrasound imaging remains problematic due to severe aberrations caused by the skull. Wide-aperture 2D arrays can help to achieve usable imaging resolution by compensating for aberration effects. In the experiments, a skull phantom was made from epoxy resin mixed with aluminum oxide powder. The phantom had the following parameters: density 1.4 g/cm^3, longitudinal velocity 2.6 mm/µs, shear velocity 1.3 mm/µs, and absorption coefficient 4 dB/cm at 1 MHz, 7 dB/cm at 2 MHz. The phantom thickness was made nonuniform with one side being flat and the other side having profile variations similar to human skull. To simulate the "flash-mode" imaging regime, the skull phantom was insonified from the flat side by a short 2-MHz tone burst emitted by a broadband wide-aperture (several cm diameter) flat source. A needle hydrophone was raster scanned in a plane region proximal to the skull phantom. The corresponding synthetic array was of 100×100-element size and 0.5 mm pitch. Several mm-sized scatterers were placed in water at 3-4 cm distance from the other side of the phantom. The imaging consisted of two steps. In the first step, the skull phantom thickness was mapped using echo arrival time differences between the front and back surfaces (Figure 2). Then the 3D image was built based on a delay-and-sum algorithm. The image was built both without and with account for the presence of the inhomogeneous skull phantom. Typical image improvement can be seen in Figure 3: the lateral resolution was significantly improved when the aberrations were accounted for in the procedure.

CONCLUSIONS

Synthesizing a 2D array with a large number of elements can be effectively done even with a single hydrophone. To mimic the array, a hydrophone placed in the desired array elements' locations by a computer-controlled positioner can be used. Array synthesis is possible and effective if the acoustic field under study can be generated repeatably with high accuracy. Capturing acoustic field measurements in 2D provides detailed information about 3D fields in both CW and transient regimes. This information has practical utility in both therapeutic and imaging applications. The work was supported by the Russian Science Foundation grant no. 14-15-00665 and NIH R21EB016118.

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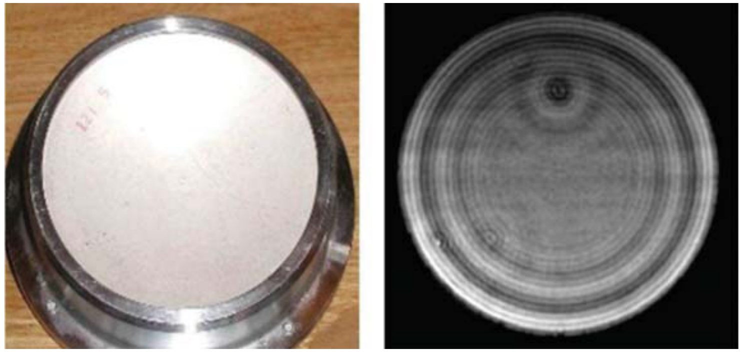

Figure 1: Piezoelectric transducer (*left*) and distribution of the particle velocity magnitude on the transducer surface while operating in the transient regime (*right*).

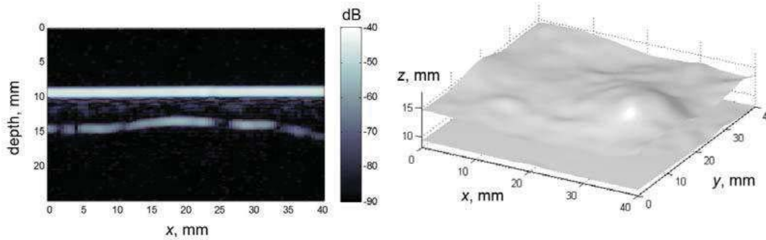

Figure 2: Skull phantom thickness pulse-echo measurements. *Left*: typical B-mode image in a transversal plane. *Right*: phantom back-side profile reconstructed from the pulse-echo measurements.

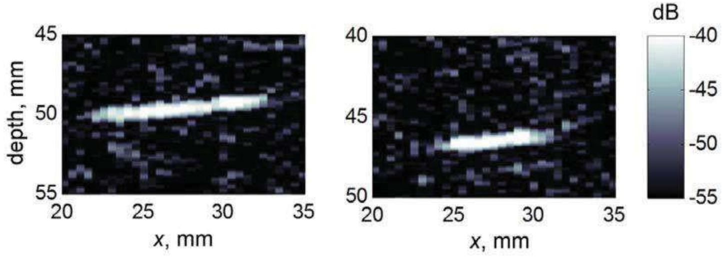

Figure 3: B-mode image of a 2-mm diameter spherical scatterer placed behind the skull phantom. *Left*: image constructed without account for the inhomogeneous layer. *Right*: image reconstructed with account for the layer.