Acoustical Compressive 3D Imaging with a Single Sensor

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Background, Motivation and Objective

3D ultrasound (US) requires expensive transducers comprising thousands of elements and complicated hardware. This complexity originates from the classical idea on spatial sampling requirements for US imaging. The discovery of compressive sensing allows to ease this sampling constraint, enabling smarter ways of recording the required information. Inspired by this work we introduce a US imager that can perform 3D imaging using one acoustic sensor. Our device sends and detects US waves through a random coding mask that enables unique signals at every voxel. Rotation of the mask allows for several compressed measurements. By knowing the voxel signals, a full 3D reconstruction of the object can be obtained, as we demonstrate in this work.

Statement of Contribution/Methods

The coding mask was made from plastic with 1mm holes drilled with varying depths. This variation in depth causes the transmit and receive acoustic field to produce a unique interference pattern. We used a commercial single element transducer (5 MHz, 17mm, C309-SU Olympus) coupled to a pulser/receiver box (5077PR – Olympus). For calibration purposes we recorded the transmit field in a plane perpendicular to the acoustic propagation axis using a hydrophone (0.5 – 20 MHz Precision Acoustics). To estimate the signal originating from every voxel we used the angular spectrum approach to calculate resulting voxel signals at greater depth; auto-convolution to account for the pulse-echo acquisition; and linear interpolation to account for additional rotation measurements. We formalized our image reconstruction problem in a set of linear equations $\mathbf{Ax} = \mathbf{y}$, where $\mathbf{A}$ is the system matrix (obtained from calibration), $\mathbf{y}$ contains our pulse-echo measurements and $\mathbf{x}$ is the recovered image. The image was found by iteratively minimizing the least-squares error between $\mathbf{Ax}$ and $\mathbf{y}$ using the MATLAB LSQR algorithm. For the imaging experiment we placed two 3D printed plastic letters ‘E’ and ‘D’ inside water.

Results/Discussion

Figure 1(a) shows a schematic overview of our imaging device and setup, Fig1(b) the mean projections of the two reconstructed letters. We used 72 rotations and 15 LSQR iterations. Future work includes optimal mask design to mitigate the need for mask rotation. In this paper we presented the first hardware implementation of compressive 3D US imaging consisting of one acoustic active element and a random coding mask.

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