Single-element 3D ultrasound imaging with compressive sensing

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Feb 17, 2021
EE 367 Project Proposal

Motivation

Ultrasound imaging is one of the most widely-used modalities for biomedical imaging due to its safety and relatively low cost compared to other imaging modalities. However, 3D ultrasound imaging remains quite expensive because it traditionally requires a 2D array of transducer elements in order to focus an ultrasound beam in 3D space. In order to satisfy the Nyquist sampling theorem, these arrays must have elements with $\lambda/2$ or smaller spacing in order to adequately sample the spatial profile of the backscattered ultrasound waves. Therefore, the cost of an array with many elements along with the associated electronics for amplification and digitization can be quite high.

Compressive sensing techniques enable image reconstruction from measurements with sub-Nyquist sampling, so long as the target image is sparse in some domain. A consequence of this is that it is possible to reconstruct a 3D ultrasound image from data captured by a single transducer, without any form of mechanical scanning [1].

In general, this problem is ill-posed, since a single transducer will integrate the incident pressure field across the entire area of the transducer, so it is impossible to map the received signal to a localized target point. However, a coded aperture in the form of a random phase mask can be used to break the phase uniformity of the incident pressure field such that different temporal signatures can be mapped to different points in space. If the image formation model is known (through calculation or calibration), then it is possible to reconstruct the original image from a highly sub-Nyquist measurement with a regularized least squares inversion. The regularizer is used to impose priors on the reconstructed image, such as sparse gradients.

Related Work

Rather than a random phase mask, it is possible to use a binary coded mask with a cyclic Hadamard pattern [2]. Localization of a target can also be achieved by exploiting the presence of random acoustic scatterers in the medium [3].

Project Overview

In this project, I will first simulate a 2D imaging geometry with a single transducer, random phase mask, and various targets in an acoustic wave simulator such as Field II or k-wave. I will implement an image reconstruction algorithm by calculating the image formation model and then performing a least squares inversion with a regularizer such as anisotropic TV. If time permits, I will extend the simulation to a 3D imaging geometry and also try using a cyclic Hadamard pattern instead of a random phase mask.

Milestones, Timelines, & Goals

- *Week 7:* Derive the image formation model for the random phase mask in a simplified 2D imaging geometry.
- *Week 8:* Setup the imaging geometry with the random phase mask in an acoustic simulator, and collect simulated sensor data for various targets.
- *Week 9:* Perform image reconstruction on the simulated data using a regularized least squares inversion.
- *Week 10:* Extend imaging geometry and reconstruction algorithm to 3D. Perform imaging with a cyclic Hadamard pattern instead of a random phase mask.

References

[1] P. Kruizinga, et al, "Compressive 3D ultrasound imaging using a single sensor", Science Advances, Vol. 3, No. 12, December 2017.
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[2] E. Hahamovich, A. Rosenthal, "Ultrasound Detection Arrays Via Coded Hadamard Apertures", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 67, Issue 10, Oct. 2020.
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[3] X. Luís Deán-Ben, et al, "Acoustic Scattering Mediated Single Detector Optoacoustic Tomography", Physical Review Letters, Vol. 123, Iss. 17, 25 October 2019.
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