EE367 Project Proposal

Kaitlyn Liang

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1 Motivation

Ultrasound imaging is one of the most commonly used modalities in the field of medical imaging. Pressure waves of frequencies 1-20 MHz are transmitted into the human body via piezoelectric crystals. The pressure waves will be absorbed, and reflected at any tissue inhomogeneity or interface. The received pressure waves on the same piezoelectric crystal will create an image that reflects the imaging region's tissue morphology.

Traditional ultrasound imaging techniques, while effective for a wide range of diagnostic applications, often create noisy images with speckle noise, signal attenuation, and artifacts arising from multiple reflections and diffraction. These challenges create coherent artifacts, and hinder the accurate characterization of tissue properties or the detection of small lesions. Speckle noise has been reduced in previous work by imaging the same region at different angles or frequencies. However, these require several measurements that take significantly longer to measure. Therefore, the goal is to reconstruct an ultrasound image using the smallest number of measurements and inverse modelling.

Any ultrasound measurement corresponds to a respective sample in k-space (x,z) based on the transmitted frequency, speed of sound, and location of the scatterer:

$$k_z = \frac{2f_z}{c} \qquad k_x = \frac{2x}{\lambda z}$$

f_z is the transmitted frequency of the ultrasound wave, and x and z are the distances between the two detectors, and the distances from the detector plane to the source. By transmitting ultrasound waves at different angles and frequencies, we will be able to sparsely sample k-space. Sampling all of k-space would entail measuring the response of a scatterer at all different frequencies, and receiving at all different angles and depths.

2 Related Work

Sub-sampling the Fourier domain has been used in MRI very effectively for compressed sensing techniques [Lus+08]. However, the same algorithms cannot be applied to the above work due to the small number of measurements. Sub-sampling in the spatial domain using a coded aperture has been used effectively to reconstruct 3D volumes from a single element transducer [Kru+17]. Compressed sensing in the spatial and frequency domain has also been simulated using in vivo and synthetic data for ultrasound image reconstruction [Qui+10]. Lastly, the data will be most similar to the sparsely sampled k-space VLBI data measured in the EHT Collaboration's Black Hole Image Reconstruction where inverse and forward modelling are implemented to recreate an image of a black hole [Col+19].

3 Project Overview

By transmitting a beam at different frequencies, and locations around a receiver, we will be able to sub-sample in frequency domain of US measurements. Since only 5 different transmit beams will be used, we will be able to sample the Fourier domain at 10 positions. The CLEAN algorithm will then be used to approximate the rest of k-space in order to recover the whole image. Simulations using Field-II will first be used to optimize the geometry of the transmit transducers, and verify the feasibility of the project. Secondly, the project will implemented using single-element transducers, and a phased array transducer with several piezoelectric crystal elements to receive. These will both be done in 2D.

4 Milestones, Timeline, and Goals

1. Week 7: Simulate starting geometry in Field II.
2. Week 8: Implement CLEAN algorithm, and verify with ground truth of simulated data
3. Week 9: Set up experimental apparatus using the phased array, single-element transducers, and a water bath
4. Week 10: Reconstruct the synthetic aperture image using the measured data.

References

[Lus+08] Michael Lustig et al. "Compressed sensing MRI". In: *IEEE signal processing magazine* 25.2 (2008), pp. 72–82.

[Qui+10] Céline Quinsac et al. "Compressed sensing of ultrasound images: Sampling of spatial and frequency domains". In: *2010 IEEE Workshop On Signal Processing Systems*. 2010, pp. 231–236. DOI: 10.1109/SIPS.2010.5624793.

[Kru+17] Pieter Kruizinga et al. "Compressive 3D ultrasound imaging using a single sensor". In: *Science Advances* 3.12 (2017), e1701423. DOI: 10.1126/sciadv.1701423.

[Col+19] Event Horizon Telescope Collaboration et al. "First M87 event horizon telescope results. IV. Imaging the central supermassive black hole". In: *arXiv preprint arXiv:1906.11241* (2019).