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Neural Volumetric Reconstruction for Coherent Synthetic Aperture Sonar

Synthetic aperture sonar (SAS) is an active acoustic imaging technique that coherently combines data from a moving array to form high-resolution imagery, especially of underwater environments. The moving array in SAS collects both magnitude and phase information which allows coherent integration methods to achieve resolution parallel to the sensor path that is independent of range. These high-resolution SAS reconstructions are important for applications in target localization, monitoring man-made, and biological structures.

However, reconstructing SAS imagery from measurements is an under-constrained problem. First, SAS scenes are often undersampled due to the slow propagation of sound relative to the traveling velocity of the sensor platform. Second, SAS transducers (transmitter and receiver) are bandlimited, limiting the ability to reconstruct arbitrarily fine spatial frequencies in imagery. Existing SAS reconstruction algorithms do not use analysis-by-synthesis optimization for reconstruction. Instead, SAS reconstruction coherently combines measurements (in either the time or frequency domain) to focus acoustic energy into the scene. Post-processing optimizations are then used (e.g., image-space deconvolution, autofocus, etc.) seeking to improve already reconstructed SAS images.

Researchers at Arizona State University, Dartmouth College, and Penn State University have developed an analysis-by-synthesis method for coherent synthetic aperture sonar (SAS) reconstruction. This algorithm leverages implicit neural representations to estimate acoustic scatterers in a 3D volume. Analysis-by-synthesis optimization allows us to incorporate the physics of the measurement formation, various noise models, and scene priors into the reconstruction. This algorithm is not restricted to any particular spatial sampling pattern.

Related publication: Neural Volumetric Reconstruction for Coherent Synthetic Aperture Sonar

Potential Applications:

- Reconstruction technique for synthetic aperture radar and for other coherent imaging fields (e.g., radar and ultrasound) used in fields like:
  - Underwater Imaging
  - Robotics
  - Navigation
  - Autonomous vehicles

Benefits and Advantages:

- Inspired by traditional NeRF techniques but varies significantly in terms of sampling (ellipsoidal vs. line sampling) and output (intensity vs. time series)

- Multiple experiments performed on simulated and hardware-measured data (e.g., real in-water measurements from a field survey of a lakebed) to show quantitative and qualitative outperformance over traditional techniques
- Advancing SAS imaging by providing a framework for implementing custom priors into SAS image formation process