# STUDIES ON UNDERWATER 3D ACOUSTIC IMAGING

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## Abstract

Underwater acoustic imaging (UAI) has become a critical technology in various marine application domains, including oceanography, underwater navigation, environmental monitoring, and defence. The existing imaging systems have contributed significantly but continue to encounter challenges such as high hardware overhead, target ambiguity, limited angular and range resolutions, requirement of platform motion for 3D imaging, signal degradation in noisy or reverberant waters, etc.

In response to these limitations, this thesis proposes a system for underwater 3D acoustic imaging with significantly reduced transducer and electronics hardware complexity compared to planar arrays, while also mitigating target ambiguity commonly associated with Mills Cross receiver configurations. The proposed system is a novel integration of Mills Cross transceiver array architecture with good correlation waveforms, enabling single-shot transmission of all elevation beams, two-step receiver processing involving azimuth beamforming followed by cross-correlation based elevation beam decoding that achieves 3D imaging without platform motion.

To enhance reconstructed 3D image quality, we explored deconvolution techniques. Deconvolution Approach for Mapping of Acoustic Sources (DAMAS), originally developed for aeroacoustics, is the only deconvolution technique known to have been applied in UAI, with a single documented use in the literature to the best of our knowledge. However, it is identified that DAMAS always has one of the following two limitations based on the transmit waveform duration: a long-duration signal improves angular resolution but degrades range

resolution, while a short duration signal preserves range resolution but leads to severe image distortion, particularly at the edges of the azimuth and elevation Field of View (FOV).

To overcome these limitations, a novel Linear Frequency Modulated (LFM) pulse based Time Domain Deconvolution (LTDD) method, is developed for planar receiver arrays. It exploits the pulse compression property of LFM to enhance range resolution, while the long pulse duration ensures sufficient signal overlap across sensor pairs for accurate beamforming, thus improving angular resolution. In contrast, the DAMAS algorithm is not compatible with LFM waveforms due to its non-linear formulation and inherent non-negativity constraint.

The second novel time domain deconvolution technique is tailored for the proposed Mills Cross transceiver based imaging system. The system exhibits high sidelobes in azimuth due to conventional beamforming and even higher in elevation due to additional effect of spatial leakage from adjacent elevation beams. The proposed method mitigates these distortions simultaneously across azimuth, elevation and range dimensions.

In addition to enhancing image resolution, this study addresses the challenge of extending the maximum imaging range under low input Signal-to-Noise Ratio (SNR) conditions. The three deconvolution based image enhancement techniques were found to be effective only above a specific of SNR, beyond which their performance deteriorates significantly. To improve their applicability at lower input SNRs, a sensor-level SNR enhancement method is proposed. This approach is analytically supported by sonar equation analysis, which links environmental and system parameters to the achievable maximum imaging range of the UAI system.

Overall, this research aims to advance the field of 3D UAI by integrating multiple key proposals into a cohesive and unified system framework. The resulting imaging system achieves single-shot 3D imaging with significantly reduced transducer and hardware complexity and reduced target ambiguity, and simultaneous resolution enhancement in all three spatial dimensions while minimizing image distortions through an efficient two-step receiver processing strategy. All the simulation results are verified with the laboratory based tank experiments.