Processing Methods for Left-Right Ambiguity Resolution in Twinline Towed Array Sonar

Abstract

A linear array with omnidirectional sensors cannot discriminate between the azimuth angle and its complementary angle due to axisymmetry about the array axis. This thesis examines solutions to the bearing ambiguity problem known as Left-Right (LR) ambiguity using two closely spaced parallel arrays. Second-order Nulling (SoN) beamformer is designed to produce a cardioid-type spatial response with a null that is electronically steered to the complementary angle of the direction of interest. The performance is evaluated in correlated noise conditions modelled by a first-order auto-regressive process.

This work establishes analytical results for the bound on the detection gain of the two parallel arrays in terms of the Rayleigh quotient of the circulant noise correlation matrix. A closed-form expression is developed for estimating the loss due to cardioid processing at small inter-array spacing. Twin array processing using the 2-Dimension Direct Beamformer (2DDB) method results in a higher Detection Gain (DG), while cardioid-based beamformers give a higher Rejection Ratio (RR). From the field data, approximately 19 dB Left-Right discrimination is demonstrated at 1650 Hz for the broadside. Experimental results from a towed array corroborate the analysis and simulations.

In the second problem addressed in the thesis, the role of a sparse array, specifically the Coprime Sparse Arrays (CSA) on the twin array is examined. CSA with two collocated Uniform Linear Array (ULA) are used to estimate $O(MN)$ direction of arrivals for a narrow band source with only $O(M + N)$ sensors. We design LR resolved CSA (LRCSA) to produce a null that is electronically steered to the complementary angle of the desired direction. LRCSA twin array achieves higher spatial resolution than the conventional fully populated LR array with the same number of sensors, much like the collocated CSA. Twin array processing using the LRCSA method results in narrow main lobe beamwidth along with a higher rejection ratio (RR) compared to 2DDB and NCB. Data obtained from a sea experiment using a towed array is analysed.

The performance from an adaptive beamformer-based LR ambiguity resolution with twin-array is also examined. We use an adaptive beamformer based on Minimum Variance Distortionless Response (MVDR) beamformer along with cardioid beamforming to produce a null that is electronically steered to the complementary angle of the desired direction for a twin array. We demonstrate the performance of MVDR based beamformer on a twin array in the correlated noise modelled by a first-order auto-regressive process.

This thesis also explores a Deep Neural Network (DNN) technique for LR resolution and analyses its performance. We develop a framework for the left-right resolution problem based on the probability of error in estimating the correct state (PoE). Binary classification based on DNN is used to resolve the LR ambiguity. The DNN method based on raw sensor data processing is found to be closer to the optimal performance.