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Spatial Spectrum Sparse Reconstruction for Maneuvering Towed Array

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Abstract

The port-starboard ambiguity in the conventional single towed linear array sonar is one of the most deceiving obstacles for the spatial spectrum estimation. In order to improve the performance of target detection and Direction of Arrival (DOA) estimation, a spatial spectrum sparse representation model is established using multiple beam-space measurements. The forward-backward operator splitting method is adopted for solving the sparse optimization problem. Simulation results demonstrate that, compared with Conventional Beam Forming (CBF) method, the proposed method has evident advantages in ambiguity suppression and estimation performance.

Keywords: sparse reconstruction; towed linear array; port-starboard ambiguity; forward-backward operator splitting

1. Introduction

Towed hydrophone arrays have advantages in the low frequency range together with a significant reduction of platform noise. Therefore, they are very useful for detecting silent or distant targets[1]. The conventional towed arrays comprise multiple omni-directional hydrophone elements drawn behind a vessel. It is impossible to determine which side of the vessel an underwater sound source originates from, because the signal time difference of arrival (TDOA) is same from either side, referred to as 'port-starboard ambiguity'. The port-starboard ambiguity can be resolved by changing the course of the vessel, but in many applications, the array shape is treated as a straight line which can result in large variance in the bearing estimates and influence the stable target tracking during the vessel turning. In order to resolve the port-starboard ambiguity effectively, various towed arrays are studied such as twin-line array[2], array with hydrophone triplets[3] and acoustic vector sensor array[4]. But these arrays are not used widely in military and industrial operations because of increased costs, complicated technologies and limited deployment possibilities. Therefore, how to develop methods of signal processing to realize DOA estimation without the port-starboard

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ambiguity for towed hydrophone array is still a challenging research topic. In practice, when the vessel maneuvers, the towed array may not be a true line array. The distorted array shape induced by the turning of vessel is utilized for resolving the port-starboard ambiguity[5,6]. However, the distorted array can result in reduced signal gain in the beamforming process and limited snapshot number can restrict the use of many adaptive beamforming algorithms.

Compressive sensing is a new signal sparse reconstruction technique which requires fewer measurements to reconstruct the signal, which is sparse in some basis vectors[7-10]. In this paper, a spatial spectrum sparse representation model is established with multiple beam-space measurements. The forward-backward operator splitting method is adopted for reconstructing the spatial spectrum. The proposed algorithm results in satisfactory ambiguity suppression and better estimation performance by comparing with CBF.

The outline of the paper is organized as follows. In section 2, we present the sparse array signal model for maneuvering towed array. In section 3, the details of spatial spectrum sparse reconstruction algorithm using forward-backward operator splitting is discussed. Simulation results are presented in section 4. Section 5 concludes the paper.

2. Sparse array signal model for maneuvering towed array

To simplify the subsequent discussion, the coordinate system of maneuvering towed array is illustrated in figure 1. The towed array is made up with M sensors with equal separation d. Narrowband far field source from the direction θ_q impinges on the towed array. The first sensor that is the closest to the towing vessel is located at original point.

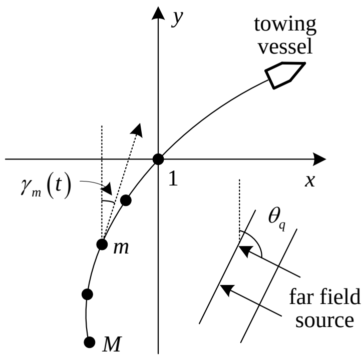

Fig. 1. coordinate system of maneuvering towed array.

When the towing vessel is turning, the array shape is distorted which can be estimated by using AR model[11]. At time instant t, the position of the sensor $m \in \{2,3,\cdots,M\}$ with course angle $\gamma_m(t)$ can be written in vector form as

$$\boldsymbol{r}_m = \left[-\sum_{i=2}^{m} d \sin\left[\gamma_i(t)\right], -\sum_{i=2}^{m} d \cos\left[\gamma_i(t)\right] \right]^T \tag{1}$$

Then we obtain the steering vector as

$$\boldsymbol{a}(\theta_q) = \left[1, \exp\left(-\mathrm{i}2\pi \boldsymbol{r}_2^T \boldsymbol{u}_q / \lambda\right), \cdots, \exp\left(-\mathrm{i}2\pi \boldsymbol{r}_M^T \boldsymbol{u}_q / \lambda\right)\right]^T \tag{2}$$

where $\boldsymbol{u}_q$ is directional vector, λ is wavelength. Based on the theory of sparse representation, the bearing angle space is uniformly discretized into Q angular directions, and the steering matrix can be written as