Abstract

A 2-Dimensional (2D) imaging sonar system has wide range of underwater applications. Underwater navigation, obstacle avoidance, surveillance, mine detection, ship hull inspection and health monitoring, underwater survey, oil and natural gas exploration etc. are some of the common applications of imaging sonar. The objective of this thesis is to investigate the synthesis of Sparse Linear Array (SLA) for forward looking 2D sonar imaging system and Direction Of Arrival (DOA) estimation of acoustic sources using sparse methods.

The main focus in this study is on the design of SLA in relation to DOA estimation methods. Conventional 2D (range-bearing) sonar imaging systems use uniform linear array of omnidirectional sensors with half wavelength spacing to avoid grating lobes. However, for high angular resolution, the uniform linear array requires fairly large number of sensors and associated electronics, which in turn increases the cost of the system and the computational load on the imaging system. The sparse (non-uniform) linear array design could be the possible solution for above problems by allowing separation larger than half wavelength while still avoiding grating lobes due to non-uniformity of sensor locations.

A detailed study has been performed to design receiver SLA. The imaging system parameters are discussed keeping obstacle avoidance application in mind. However, the designed SLA could be used in other applications also. The SLA design is proposed in far-field by considering multiple beams in the field of view and is compared with existing single beam compressive sensing method. Here, multiple beams are

referred to as multiple steering directions in the field of view. The SLA design with multiple beams in the field of view is referred to as Multiple Measurements Vector (MMV) Compressive Sensing (CS) method while the design with a single beam in the field of view is referred to as Single Measurement Vector (SMV) CS method. The limitation associated with the steering of beam in the synthesised SLA using SMV CS method results in spurious beam in the beam pattern, which is overcome by synthesised SLA by the proposed MMV CS method. The performance of the synthesised SLA has been characterized by measuring Side Lobe Peak (SLP) and Main Lobe Width (MLW) of each beam in the field of view, and percentage reduction of sensors in synthesised SLA as compared to half wavelength spacing uniform linear array. In order to generalize the SLA design using MMV CS method, the SLAs have been designed by keeping the size of aperture fixed and varying angular resolution, and vice-versa by keeping angular resolution fixed and varying the size of aperture using simulation studies for different frequencies.

A high resolution forward looking sonar imaging system operating at high frequency, say 1.2 MHz, has a short range of 10 m - 20 m. Such an imaging system cannot operate in far-field conditions, and, therefore near-field conditions become necessary to be taken into consideration. The SLA with multiple beams in the field of view focusing at a particular range has been proposed in near-field condition using compressive sensing framework. The performance of this synthesised sparse linear array has been evaluated by refocusing at various ranges in the near-field through simulation studies. The effect of mismatch in sensor locations and random failure of various sensors on the directivity pattern of synthesised sparse linear array has also been investigated.

The SLA synthesised in near-field operating at 1.2 MHz has high angular resolution of 0.22° and coarse beam spacing of 1° in the field of view -30° to 30° (61 beams). This requirement poses computational challenges for designing high angular resolution 0.22° imaging system with fine beam spacing of 0.25° (i.e. 241 beams in the

field of view) in terms of execution time and amount of system memory. The SLA is synthesised using proposed method based on Alternating Direction Method of Multipliers (ADMM) technique which overcomes the above mentioned limitations and gives comparable performance as that of MMV CS method.

The proposed methods are based on convex optimization and are mathematical optimization problems. In these optimization problems, the constraints of MLW and SLP for all beams are defined indirectly in terms of beam pattern. In order to further improve the performance of the SLA, the side lobe constraints are directly relaxed instead of defining indirectly in terms of beam pattern. The study is conducted through numerical simulations and improvements are achieved in terms of percentage MLW error. Here, we list the proposed methods for SLA design to give a more clear picture to the reader. The proposed SLA synthesis methods are MMV CS and ADMM in far-field and near-field. The relaxed sidelobe constraint method is proposed for SLA synthesis in far-field only. In this thesis, we have presented only simulation study and experiments with real data shall be done in future work.

The last part of this thesis explore the problem of SLA synthesis to DOA estimation of acoustic sources by application of CS framework applied to the DOA problem. The investigation is focused on existing conventional beamformer (CBF) (delay and sum beamformer) and compressive sensing methods: Grid Free CS and Iterative Adaptive Approach for Amplitude and Phase Estimation (IAA-APES). Grid Free CS produces a spurious estimate in the noisy scenario and thus, Grid Free CS with Bayesian Information Criterion (BIC) is proposed to produce a point estimate. The performance of these estimation methods is studied in detail through numerical simulations.